NORTHERN COLORADO PLATEAU
VITAL SIGNS NETWORK AND PROTOTYPE CLUSTER
PLAN FOR NATURAL RESOURCES MONITORING

PHASE II REPORT

September 30, 2003

Prepared by:

Mark E. Miller, Ph.D.
NCPN Program Ecologist
(currently USGS-BRD, Canyonlands Field Station)

Dave Sharrow
Zion National Park

Lynn Cudlip
Western State College

With Assistance from NCPN Staff and Technical Committee

~~~~

Northern Colorado Plateau Network
National Park Service
2282 S. West Resource Blvd.
Moab, UT 84532-3298

~~~~

Approved by:

Alford J. Banta, Chair NCPN Board of Directors Date

Angela G. Evenden, NCPN I&M Program Manager Date

IMR I&M Program Manager Date

NORTHERN COLORADO PLATEAU
VITAL SIGNS NETWORK AND PROTOTYPE CLUSTER
PLAN FOR NATURAL RESOURCES MONITORING

PHASE II REPORT

September 30, 2003

TABLE OF CONTENTS

FIGURES

TABLES

ACKNOWLEDGEMENTS

This report reflects the combined effort of a large number of dedicated resource professionals. Contributors to the Phase I report prepared a solid foundation for the vital-sign selection process summarized in this Phase II report. This report could not have been completed without the efforts of these individuals – Dr. Angie Evenden, Margaret Beer, Libby Nance, Sonya Daw, Aneth Wight, and Mike Estenson. We would especially like to thank Sonya Daw and Dr. Sam Kunkle for their prominent roles in determining the monitoring needs of NCPN parks.

The NCPN Technical Committee and park staff again have been instrumental in the continued development of this program, including the production of materials presented in this report. They participated in surveys and workshops, responded to email and telephone queries, provided critical and thoughtful review comments, and (most importantly) treated Mark Miller well during park visits. Individuals who participated in these activities over the past year include Jeff Bradybaugh, Denise Louie, Sharon Kim, Kezia Nielsen, Cheryl Decker, Steve Robinson, Kelly Cahill, Kristin Legg, Craig Axtell, Tom Clark, Dave Worthington, Andrea Bornemeier, John Hiscock, Charlie Schelz, Bruce Rodgers, Dave Price, Lisa Claussen, Ken Stahlnecker, Myron Chase, Matt Malick, Danguole Bockus, Michael Dale, Tamara Naumann, Wayne Prokopetz, Clay Kyte, Vince Santucci, Dave McGinnis, Mary Risser, Jon Jasper, Mike Gosse, Jason Mateljak, and Cami Pulham.

The NCPN Board of Directors has provided oversight for the continuing development of this program and the selection of park vital signs. We particularly appreciate critical vital-signs input from Jerry Banta, Al Hendricks, and Chas Cartwright. We also thank Dr. Ron Hiebert, leader of the Colorado Plateau Cooperative Ecosystem Studies Unit, for his contributions to the vital-sign selection process.

During her relatively short time as coordinator of the Southern Colorado Plateau Network, Lisa Thomas already has contributed substantially to the development of the NCPN program by generously sharing her ideas, experience, and humor. We thank her for her insights, and we look forward to the growing relationship between the two Colorado Plateau networks. (She should be a coauthor of this report, but we decided to spare her the embarassment.)

Dr. Jayne Belnap and Dr. Tim Graham of the U.S. Geological Survey (USGS) in Moab both seasoned the NCPN vital-signs selection process with significant amounts of wisdom and humor. We thank them and Mike Scott of USGS in Fort Collins for their engagement in repeated vital-sign evaluation exercises.

Dr. Ed Krumpe of the University of Idaho conducted the web-based Delphi survey and was a thoughtful participant in the April 2003 vital-signs workshop. Michael Anthony of the USGS in Moab developed numerous database tools that greatly facilitated the vital-sign evaluation process.

NCPN vital-sign activities over the past year have benefited greatly from the patient and thoughtful participation of six members of the scientific community. Drs. Jill Baron, Barry Noon, Buck Sanford, Jack Schmidt, Tim Seastedt, and Joe Truett provided helpful comments and insights on a variety of issues pertinent to the monitoring program. As we strive to meet their standards, we hope that they will tolerate our shortcomings and continue to work with us in the development of this program.

Kirby Wynn, Paul von Guerard, Juliane Brown, and Sharon Day of the USGS provided outstanding support to the water-quality component of this program over the past year. We particularly thank Kirby, Juliane, and Paul for their thorough review of an earlier draft of this report. It is a pleasure to work with such a professional team. We also appreciate the continued guidance and support provided by Pete Penoyer of the NPS Washington Office Water Resources Division. His efforts have significantly improved NCPN planning for water-quality monitoring.

We greatly appreciate the continued guidance and professional leadership provided by Dr. Steve Fancy, NPS National Monitoring Leader, Mike Britten, NPS Intermountain Region Inventory & Monitoring Coordinator, and Gary Williams, NPS Inventory & Monitoring Program Manager. Their support has made our work easier.

Finally, we would again like to thank and commend Dr. Angie Evenden for all of the creative energy, enthusiasm, and managerial skill that she has devoted to this program since its inception. This program would not be where it is today without her exceptional guidance. Three cheers!

EXECUTIVE SUMMARY

This document comprises the Phase II report on the development of a plan for natural resources monitoring in 16 parks of the Northern Colorado Plateau Vital Signs Network (NCPN) and Prototype Cluster. The report lists vital signs that have been identified by individual network parks, describes park-specific and network-level priorities in relation to these vital signs, and serves as documentation for GPRA Goal 1b3 – Vital Signs.

Vital Signs Definition

Vital signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).

Goals for Vital Signs Monitoring

NPS servicewide goals establish five reasons for vital-signs monitoring. These are to:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources;
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management;
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments;
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment; and
- Provide a means of measuring progress towards performance goals.

Elements of the NCPN Vital-Signs Identification Process

The following activities were key elements of the NCPN vital-sign identification process:

- Extensive park scoping conducted during the Phase I process;
- Engagement of a six-member Independent Scientific Review Panel to provide external scientific review and guidance;
- Internet-based Delphi survey to solicit vital-signs input from a broad audience of scientists and resource-management specialists;
- Vital-signs workshop for NPS staff, science partners, and other technical experts to review input and evaluate candidate vital signs;
- Application of peer-reviewed evaluation criteria to aid the selection of vital signs;
- Follow-up visits to all NCPN parks to discuss and identify park-specific vital signs; and
- Park review, revision, and approval of vital signs.

NCPN Vital Signs

NCPN vital signs are organized by an integrative set of categories that together span the concept of ecological integrity. Additional categories exist for stressor-oriented vital signs and for other natural-resource values such as paleontological resources and natural night skies. Total numbers and relative priorities of vital signs vary among NCPN parks. These variations generally reflect differences in the diversity of resources and in the complexity of resource-management concerns. Despite these differences, there are important commonalities among parks in terms of resources, issues, and monitoring needs. On the basis of these commonalities, the network as a whole has identified a subset of high-priority vital signs that will be emphasized at the network level. These are summarized in the following table.

VITAL-SIGN CATEGORY*		HIGH-PRIORITY VITAL SIGNS
Climatic conditions		Precipitation patterns and temperature patterns
Air quality		Atmospheric deposition, visibility, and tropospheric ozone levels
Soil, water, and nutrient dynamics		Upland soil / site stability, upland hydrologic function, and nutrient cycling
		Stream flow regime, stream / wetland hydrologic function, and groundwater dynamics
Water quality		Dissolved oxygen, pH, conductivity, water temperature, and flow / stage
Disturbance regimes		Fire regimes and extreme climatic events
Biotic integrity	***Predominant* plant communities**	Predominant upland plant communities
	***At-risk* species or communities**	Threatened, endangered, or sensitive vertebrate populations and plant populations
		Riparian-obligate bird communities
		Native grasslands, sagebrush shrublands, and riparian / wetland plant communities
	***Focal* species or communities** (key contributors to biodiversity and/or ecosystem function)	Riparian / wetland communities, including springs, seeps, and hanging gardens
		Biological soil crusts and aquatic macroinvertebrates
	***Endemic* species or *unique* communities**	Hanging-garden communities
		Rare / endemic plant populations
Landscape-level patterns		Land cover, land use, park insularization, landscape fragmentation and connectivity
Stressors		Park use by visitors, invasive exotic plants, and adjacent / upstream land-use activities

*Because of the complex nature of ecosystems, there is considerable overlap among vital signs categories.

Next Steps

Material presented in this Phase II report will be used as the basis for the Phase III report, which will focus on sampling design, sampling protocols, data analysis and reporting, and implementation time-frames for selected high-priority vital signs. The first (peer-review) draft of the Phase III report is due by December 15th, 2004.

NORTHERN COLORADO PLATEAU
VITAL SIGNS NETWORK AND PROTOTYPE CLUSTER
PLAN FOR NATURAL RESOURCES MONITORING

PHASE II REPORT

INTRODUCTION

This document comprises the Phase II report on the development of a plan for natural resources monitoring in parks of the Northern Colorado Plateau Vital Signs Network (NCPN) and Prototype Cluster. National Park Service (NPS) vital-signs monitoring plans are organized as follows:

Chapter I.	Introduction and Background
Chapter II.	Conceptual Ecological Models
Chapter III.	Vital Signs
Chapter IV.	Sampling Design
Chapter V.	Sampling Protocols
Chapter VI.	Data Management
Chapter VII.	Data Analysis and Reporting
Chapter VIII.	Administration and Implementation of the Monitoring Program
Chapter IX.	Schedule
Chapter X.	Budget
Chapter XI.	Literature Cited
Chapter XII.	Appendices

The Phase I report (issued October 1, 2002) on the development of the vital signs monitoring plan contained drafts of chapters I, II, VI, VIII, and XI, as well as numerous supporting appendices (Evenden et al. 2002). (Note that the chapter numbering scheme has been revised since the Phase I report.) Reviews of the NCPN Phase I report by the NPS Washingtion Office and Intermountain Region Office did not require the Phase II report (this report) to contain changes to draft chapters presented in the Phase I report. As a consequence, this Phase II report primarily consists of a first draft of Chapter III, specifying prioritized sets of vital signs identified by NCPN parks. This report also includes several appendices pertaining to vital-signs selection and other aspects of program development that have occurred since distribution of the Phase I report. Material presented in this Phase II report will be used as the basis for the Phase III report, which will include revisions and updates to previously submitted chapters as well as first drafts of remaining chapters. Emphasis of the Phase III report will be on sampling design, sampling protocols, data analysis and reporting, and implementation time-frames. The first (peer-review) draft of the Phase III report is due by December 15th, 2004.

III. VITAL SIGNS

Introduction

The ultimate purposes of this chapter are to present the prioritized sets of vital signs identified by individual NCPN parks and to discuss network-level vital-signs priorities identified on the basis of cross-network commonalities and previously identified program emphases. To set the stage, this chapter begins with a brief background section that describes the rationale for the NCPN vital-signs framework. Following the background section, the process and criteria used to identify vital signs are summarized. Additional details regarding the vital-signs evaluation and identification process are provided in appendices. The remaining balance of the chapter focuses on the vital signs themselves, including a network-level overview and park-specific tables. Water quality vital signs are presented and discussed separately from all other vital signs.

Background

This section reviews factors that have contributed to the structure of the NCPN vital-signs framework. Most of these factors were presented in the Phase I report, but they are reviewed briefly here to support the vital-signs discussion. This section concludes by presenting the hierarchical framework used to organize the vital-signs discussion.

Factors Contributing to the NCPN Vital-Signs Framework

Several related factors have contributed to the structure of the NCPN vital-signs framework. These include NPS goals for vital-signs monitoring, NPS management policies concerning the maintenance and restoration of *ecosystem integrity*, monitoring themes previously identified by the Northern Colorado Plateau (NCP) Prototype, and significant resources identified by the NCPN.

Vital Sign Definition

Vital signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes) (from NPS Inventory and Monitoring website, http://science.nature.nps.gov/im/monitor/vsm.htm#Definitions). Defined in this way, vital signs *may or may not be* indicators of overall ecosystem condition.

NPS Goals for Vital Signs Monitoring and the Concept of Ecological Integrity

The NPS servicewide goals establish five reasons for vital-signs monitoring. These are to:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources;

- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management;
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments;
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment; and
- Provide a means of measuring progress towards performance goals.

NPS management policies dictate that the Service will use monitoring data "...to maintain—and, where necessary, restore—the integrity of natural systems" (NPS 2001:31). Thus the NCPN interprets servicewide goals for vital-signs monitoring within the context of NPS management policies pertaining to the maintenance and restoration of *ecological integrity*.

The NPS Inventory and Monitoring Program (I&M Program) defines *ecological integrity* as a concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self-renewal. Ecological integrity implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes (http://science.nature.nps.gov/im/monitor/Glossary.htm).

Prototype Monitoring Themes and the Jenny-Chapin Model

During the early stages of program development, the NCP Prototype identified three themes that would be emphasized in the prototype program: (1) ecosystem structure and function, (2) invasive plants, and (3) threatened, endangered, and sensitive (TES) plants and animals (Phase I report, Appendix V). These themes were identified on the basis of critical monitoring needs expressed by park staff. For purposes of vital-signs planning, these three prototype themes also have been applied to the network program.

In the Phase I report, the NCPN adopted a modified version of the Jenny-Chapin model (also referred to as the "interactive-control model," Chapin et al. 1996) to provide a robust general framework for the ecosystem theme. The Jenny-Chapin model identifies four interactive controls that must be conserved within their "natural" ranges of variability in order to sustain the structural and functional characteristics of ecosystems (see Appendix J for definitions of key terms and concepts). These four interactive controls are (1) atmospheric resources and conditions, (2) soil and water resources and conditions, (3) disturbance regimes, and (4) biotic functional groups. On the basis of this model, the NCPN identified the interactive controls and their components as key elements to be included in ecological conceptual models (see Appendix I) and the overall framework for organizing candidate vital signs.

Sustainability – the emphasis of the Jenny-Chapin model – is encompassed in the notion of ecosystem integrity, but sustainability alone is an insufficient criterion for integrity because the latter concept implies a higher standard of ecological condition (Karr 1996, 2000), particularly with respect to biotic components of ecosystems. For concepts such as ecosystem health, sustainability and integrity to be operational for purposes of assessment and monitoring, the

NCPN recognizes that reference conditions and sites must be identified where possible to establish explicit benchmarks (Karr 2000).

Significant Resources of the NCPN

In the Phase I report, the NCPN identified a set of significant ecological resources that would be emphasized in vital-signs monitoring. Water quality, air quality, and threatened and endangered species are certainly significant from a legal perspective. Resource significance can also be established on the basis of three additional perspectives: (1) ecoregional distinctiveness, (2) ecological functionality, and (3) degree of peril on a regional or nationwide basis. There is overlap among these. In all cases below, the significant resource identified in *italics* is considered to include the ecosystems, ecological processes, and conditions required to sustain the existence of that resource. Ecosystems identified as significant from these three perspectives represent a subset of the major ecosystem types identified and described in the NCPN Phase I report (e.g., Table 11 in Evenden et al. 2002).

1. Ecoregional Distinctiveness
    - *Endemic plants*
    - *Hanging garden ecosystems*

2. Ecological Functionality
    - *Air quality*
    - *Soil quality*
    - *Water quality*
    - *Biological soil crusts*
    - *Riparian, wetland and aquatic ecosystems* (including springs, seeps, hanging gardens, and tinajas)

3. Critically Imperiled Ecosystems of the Intermountain Region (Noss et al. 1995, Christensen et al. 1996)
    - *Native grassland ecosystems*
    - *Sagebrush shrubland and shrubsteppe ecosystems*
    - *Large stream and river ecosystems*
    - *Riparian forest ecosystems*

With the Southern Colorado Plateau Network (SCPN), the NCPN has explicitly incorporated these three resource categories into the overall framework for organizing candidate vital signs (presented below). Ecoregional distinctiveness is captured in the vital-sign category pertaining to endemic species and unique communities. With TES species (a prototype theme), regionally imperiled ecosystems are included in the vital-sign category pertaining to at-risk species and communities. Species, communities, and ecosystems that are particularly important from a functional perspective are included in the vital-sign category pertaining to focal species and communities.

The term *focal* requires clarification. For purposes of this report, *focal species or organisms* are defined as species or organisms that play significant functional roles in ecological systems by their disproportionate contribution to the transfer of matter and energy, by structuring the environment and creating opportunities for additional species or organisms, or by exercising control over competitive dominants and thereby promoting increased biological diversity (derived from Noon 2003:37). This definition encompasses the concepts of keystone species, umbrella species, and ecosystem engineers. *Focal ecosystems or communities* are ecosystems or communities that play significant functional roles in landscapes by their disproportionate contribution to the transfer of matter and energy, or by their disproportionate contribution to landscape-level biodiversity.

Hierarchical Vital-Signs Framework

Together, the NCPN and SCPN have adopted a hierarchical framework for vital-signs monitoring (Fig. 1) that follows the approach of Harwell and colleagues (Harwell et al. 1999). This hierarchy links overall NPS management goals with a set of ecosystem characteristics that encompasses prototype monitoring themes, interactive controls of the Jenny-Chapin model, and the types of significant resources identified by the NCPN and SCPN. These characteristics are consistent with overarching NPS management goals of maintaining and restoring the ecological integrity of park lands and relate directly to more-specific park management objectives (Table 1). Nested within this set of ecosystem characteristics are monitoring *endpoints* – ecosystem attributes of particular ecological and/or societal importance (Fig. 1).

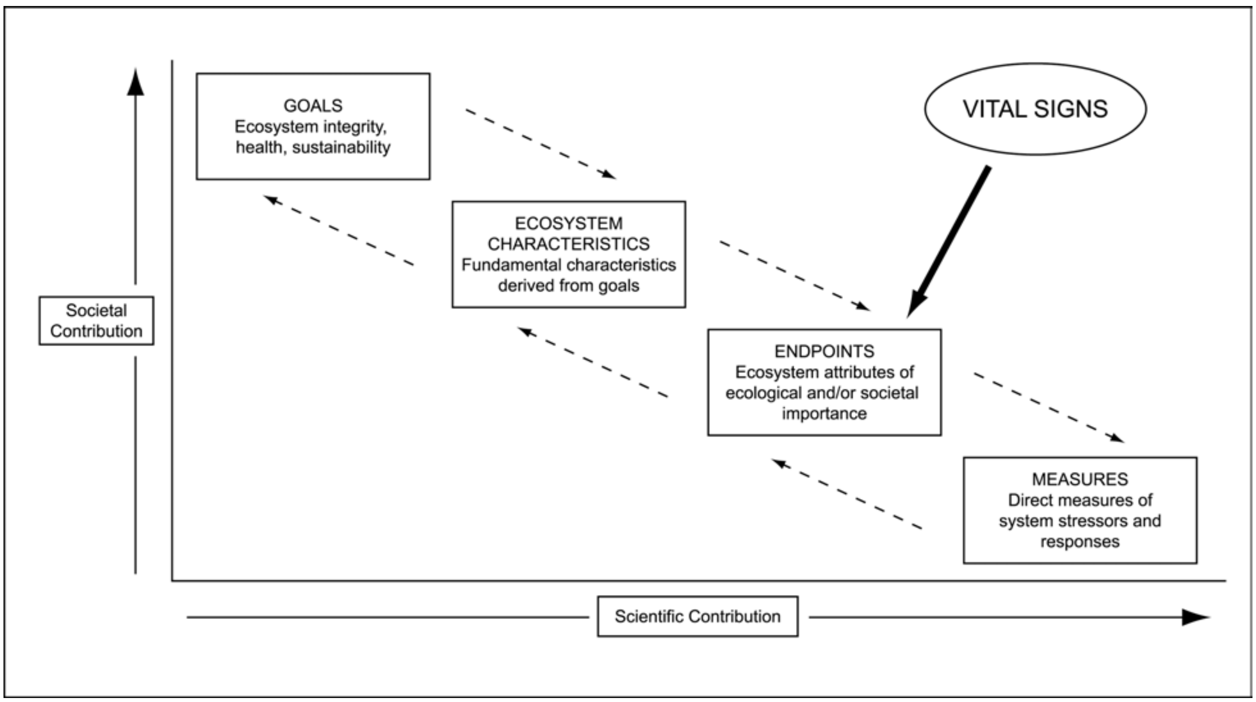


Figure 1. Relationships among societal goals, ecosystem characteristics, endpoints, and scientific measures in ecological assessment and monitoring. Societal values have a dominant role in establishing goals, and scientific issues have a dominant role in selecting measures. Ecosystem characteristics and monitoring endpoints are formed at the juncture of societal and scientific considerations (modified from Harwell et al. 1999). The NCPN interprets vital signs as equivalent to endpoints.

As currently interpreted by the NCPN, monitoring endpoints are equivalent to vital signs. *Measures* are the specific variables that are used to quantify the condition or status of particular monitoring endpoints. Depending on site-specific conditions or questions, different measures may be used to quantify the status of a single monitoring endpoint. Societal values play a dominant role in determining overall goals whereas scientific issues play a dominant role in determining the most appropriate measures for particular endpoints. Ecosystem characteristics and monitoring endpoints are formed at the juncture of societal and scientific considerations (Harwell et al. 1999).

Ecosystem characteristics serve as organizational categories for NCPN vital signs (Table 1). The categories are not mutually exclusive, and there is considerable overlap among them (endemic and at-risk species, focal and at-risk communities or ecosystems, climatic conditions and disturbance regimes, etc.).

Table 1. Management objectives and related landscape or ecosystem characteristics associated with the overall NPS goal of maintaining and restoring ecological integrity. Ecosystem characteristics serve as organizational categories for NCPN vital signs.

<table>
<tr><th>Management objectives</th><th colspan="2">Ecosystem characteristics (vital-sign categories)</th></tr>
<tr><td>Understand the role of climatic cycles, trends, and events in driving ecosystem processes and changes.</td><td colspan="2">Climatic conditions</td></tr>
<tr><td>Improve and protect regional air quality.</td><td colspan="2">Air quality</td></tr>
<tr><td>Protect soil resources and processes, and restore soil quality of disturbed lands.</td><td colspan="2" rowspan="2">Soil, water, and nutrient dynamics</td></tr>
<tr><td>Restore or maintain hydrologic function and protect ground and surface water quality and quantity.</td></tr>
<tr><td>Reduce pollution in park water bodies and protect the quality of pristine waters.</td><td colspan="2">Water quality</td></tr>
<tr><td>Understand the role of natural disturbances in driving ecosystem processes and changes.</td><td colspan="2" rowspan="2">Disturbance regimes</td></tr>
<tr><td>Restore fire-adapted systems.</td></tr>
<tr><td rowspan="4">Provide for resilient, sustainable populations and communities of native species.

Restore the structure, native species composition and natural processes of disturbed lands.</td><td rowspan="4">Biotic integrity</td><td>Status of predominant plant communities</td></tr>
<tr><td>Status of at-risk species or communities</td></tr>
<tr><td>Status of focal species or communities</td></tr>
<tr><td>Status of endemic species or unique communities / ecosystems</td></tr>
<tr><td>Provide the spatial extent, mosaic landscape pattern and connectivity required to support the natural diversity of ecosystems and species.</td><td colspan="2">Landscape-level patterns</td></tr>
</table>

In addition to vital-sign categories associated with particular ecosystem characteristics, two other vital-sign categories are included in the NCPN framework (Table 2). These pertain to stressor-oriented monitoring and monitoring of important natural resource values that fall outside the ecosystem framework presented in Table 1.

Process and Criteria for Vital Signs Evaluation and Identification

The identification of vital signs for 16 NCPN parks collectively characterized by a wide diversity of biophysical environments and management issues was a challenging exercise. This section summarizes the process and criteria used to evaluate and identify park vital signs, excluding those associated with water quality. Additional details concerning the evaluation and identification process are provided in Appendix A. The process used to identify water-quality vital signs is described separately in the water-quality portion of this chapter and in Appendix C.

Table 2. Management objectives associated with vital-sign categories pertaining to stressor-oriented monitoring and natural-resource values that fall outside the ecosystem framework of Table 1.

Management objectives	Other vital-sign categories
Prevent new establishment of non-native species and reduce the spatial extent and abundance of established non-native species to levels necessary to achieve other conservation goals.	Stressors
Understand and minimize the role of human activities in driving ecosystem processes and changes.	
Maintain or restore conditions required to protect and sustain paleontological resources, cave formations, and aesthetic resources.	Other natural resource values

Phase I Scoping

Scoping conducted during development of the Phase I report formed a fundamental foundation for the identification of park vital signs. The NCPN monitoring-needs database, developed on the basis of substantial input provided by park staff (see p. 17 and Appendix H of Phase I report), was used throughout the vital-signs identification process to ensure that previous park input was fully represented. Similarly, the synthesis of park management and monitoring issues presented in Appendix O of the Phase I report was a key information source that informed the vital-signs process. The report from the geoindicators workshop held in Moab during June 2002 (Appendix K) was another important element of Phase I scoping that was used to inform the vital-signs identification process.

Delphi and Workshop Vital-Sign Evaluation Process

Subsequent to the Phase I report, an internet-based Delphi process was an important tool used by the NCPN to solicit vital-signs input from a broad audience of scientists and resource-management specialists. The Delphi technique "...may be characterized as a method for structuring a group communication process so that that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" (Linstone and Turoff 1975:3). The Delphi method has been used elsewhere as an approach for obtaining input regarding the design of resource monitoring programs (e.g., Davis 1997; Oliver 2002a,b). In cooperation with the University of Idaho, the NCPN conducted two rounds of internet-based Delphi surveys in which over 200 invited participants were asked to provide input to the identification of NCPN vital signs. Following the Delphi survey, candidate vital signs were evaluated by NPS staff and cooperators through an additional electronic survey and a vital-signs workshop.

Delphi Round 1

In late January 2003, 237 scientists and resource-management specialists (including NPS staff from NCPN and elsewhere) from 13 categories of technical expertise were invited to participate in the first round of the NCPN Delphi survey. The survey was developed by NCPN staff and hosted on a website designed by cooperators from the University of Idaho (http://www.cnr.uidaho.edu/wilderness/NCPN/NCPNSurvey.htm). The survey was designed as a structured, electronic "brain-storming session" (Oliver 2002a) in which participants were invited to provide input regarding measurable ecosystem attributes to be considered as potential indicators for monitoring the health of terrestrial, riparian, wetland and aquatic ecosystems managed by NCPN parks. The organizational framework for the first survey was developed on the basis of the Jenny-Chapin model of ecosystem sustainability. As a consequence, the survey itself was very ecosystem-oriented and was not well-suited for obtaining input about particular species of concern, stressors, or non-ecological resource values. Of the 237 invited participants, 64 persons contributed to the survey. Results from the first survey were synthesized by NCPN staff, and this synthesis was the foundation of the second round of the survey. (See Appendix A for further details on the Delphi process.)

Delphi Round 2

In early March 2003, the same set of scientists and resource-management specialists were invited to participate in the second round of the NCPN Delphi survey. In the second-round survey (http://www.cnr.uidaho.edu/wilderness/NCPN/NCPN2ndSurvey.htm), the NCPN presented participants with a categorized set of 312 environmental attributes and measures (candidate vital signs) synthesized from scientific literature and input provided during the first-round Delphi survey (see Appendix Table A-5 for a full list of attributes and measures). Organizational categories (Appendix Table A-4) were similar to those currently represented in the NCPN vital-signs framework (Tables 2 and 3). Participants were asked to review the subset of environmental attributes that fell within the scope of their professional expertise and to evaluate them as potential vital signs on the basis of four general evaluation criteria derived from NPS I&M Program guidance and scientific literature[1]:

1. Management Significance & Utility. Vital signs must provide information that is meaningful and useful to park managers. The following statements describe vital-sign characteristics pertinent to this criterion:

    - Relevant to management issues and concerns;
    - Provides information useful for management decisions;
    - Sensitive to particular stressors affecting park resources, OR vital sign itself is a stressor or driver of resource change and variability;
    - Predicts changes in resource conditions that can be averted by management actions;
    - Produces results that are easily communicated and clearly understood and accepted by scientists, policy makers, managers, and the public;
    - Produces results with recognizable implications for stewardship, regulation, and/or research;
    - If associated with species-level (or population-level) monitoring, vital sign is an attribute of a species that is legally protected, endemic, harvested, alien, or otherwise of special interest or concern;
    - Can be applied across a wide range of ecosystems and ecosystem conditions (i.e., is not restricted in application to a particular site or system).

2. Ecological Significance & Scientific Validity. Vital signs must be ecologically significant and clearly justified on the basis of peer-reviewed literature and a scientifically sound conceptual framework. The following statements describe vital-sign characteristics pertinent to this criterion:

    - Relevant to the ecological function or valued natural resource it is intended to represent, OR vital sign itself is a stressor or driver of resource change and variability;
    - Peer-reviewed literature exists to support relevance of the vital sign;

[1] Key sources for evaluation criteria: Kurtz et al. (2001), Tegler and Johnson (1999), Dale and Beyeler (2001), Herrick et al. (1995, 2002), Noss (1990), Whitford (1998, 2002), Pyke et al. (2002).

- For ecosystem-level monitoring, vital sign reflects functional status of one or more key ecosystem processes or the status of ecosystem properties that are clearly related to these ecosystem processes [Note: replace term *ecosystem* with *landscape* or *population*, as appropriate];
- For ecosystem-level monitoring, vital sign reflects the capacity of key ecosystem processes to resist or recover from change induced by natural disturbances and/or anthropogenic stressors [Note: replace term *ecosystem* with *landscape* or *population*, as appropriate];
- Signifies impending change in the ecological system (i.e., is anticipatory);

3. Feasibility & Cost of Implementation. Sampling, analysis, and interpretation of vital signs must be technically feasible and cost-effective. For purposes of vital-sign evaluation, a cost-effective vital sign is defined as one with a high benefit:cost ratio – i.e., information benefits are high relative to total costs. The following statements describe vital-sign characteristics pertinent to this criterion:

- Well-documented methods exist;
- If well-documented methods do not exist, development is technically feasible and cost-effective;
- Logistical requirements are feasibly met (includes training, travel and site accessibility, sampling time per measurement and for the number of required replicates, sample transport, sample processing and analysis, etc.)
- Full costs of implementation are low relative to benefits gained from information (includes costs associated with protocol development and pilot studies, long-term sampling, instrumentation, analysis, data management, etc.)
- If specialized knowledge and/or instrumentation is required for data acquisition or analysis, benefits gained are high relative to costs associated with specialized knowledge and instrumentation;
- Sampling does not significantly impact the site or protected organisms (i.e., is nondestructive);
- Sampling does not significantly affect subsequent measurements of the same parameter or simultaneous measurements of other parameters.

4. Signal:Noise Ratio (Response Variability). Vital signs must be characterized by patterns of variability that are well understood and possess a high signal:noise ratio. That is, variability attributable to anthropogenic stressors must be high relative to variability attributable to natural processes or measurement errors. The following statements describe vital-sign characteristics pertinent to this criterion:

- Vital sign has limited and documented sensitivity to natural variation;
- Measurement errors introduced by human observers and/or instruments during data collection, transport, analysis, and management can be controlled and estimated;
- Factors driving short-term temporal variability are understood (including natural drivers and anthropogenic stressors) and can be estimated and evaluated;
- Factors driving long-term temporal variability are understood (including natural drivers and anthropogenic stressors) and can be estimated and evaluated;
- Factors driving spatial variability in data are well understood and can be accounted for via stratification or other means;
- Vital sign is able to discriminate differences among sites along a known condition gradient, and locations in similar "condition" yield similar measurements;
- Responds to stress in a predictable, unambiguous manner;
- Provides continuous assessment over wide range of stress;
- Discriminatory ability meets data quality objectives, factoring in variability as well as precision and confidence levels desired by the program.

An important point is that these evaluation criteria (with the possible exception of Management Significance & Utility) are most appropriately applied to *measures* rather than to *endpoints*, as differentiated in the vital-signs framework presented in Figure 1. Most *attributes* presented for evaluation in the second round of the Delphi survey were more similar to *measures* than to monitoring *endpoints* or vital signs. Participants in the survey evaluated candidate measures by assigning them evaluation scores on a scale of 1-5 for each of the four criteria. Of approximately 235 invited participants, 72 persons responded to the second survey.

On the basis of evaluation scores assigned to candidate measures, the NCPN ecologist reviewed input from the second-round survey and used professional judgement to reduce the candidate set from 312 to 164 attributes or measures (see Appendix Table A-5). During the review process, it became apparent that survey participants commonly misinterpreted the concept of signal:noise ratio. Consequently, evaluation scores for this criterion were not incorporated in the overall scores used to rank and reduce the candidate set.

Pre-Workshop Vital-Sign Evaluation

In late March and early April 2003, a final round of vital-sign evaluation was conducted in preparation for the NCPN vital-sign workshop. The reduced set of candidate attributes and measures was incorporated in a MS Access database developed to facilitate the evaluation of candidates in relation to a set of 13 relatively specific criteria (Table 3). These criteria were related to the general evaluation criteria applied during the second round of the Delphi survey. The database was designed by USGS staff in Moab following examples and guidance provided by NPS I&M Program staff. (See Appendix A for additional details regarding the application of this database tool.)

Participants in this final pre-workshop evaluation round were restricted to NCPN network and park staff, key USGS and academic cooperators, and NCPN science-panel members. Participants were asked to evaluate candidate measures by assigning them evaluation scores on a scale of 0-5 for each of the 13 criteria. They also were asked to restrict their evaluations to those candidate measures and criteria that were within their scope of professional knowledge. NCPN parks were asked to submit single consolidated responses for their parks. NCPN network staff, USGS and academic partners, and science-panel members all completed the surveys from a network-wide perspective rather than on a park-specific basis.

After all of the evaluations were submitted, an automated process was used to compile the data and calculate average evaluation scores for candidate attributes and measures. For purposes of calculating an overall total evaluation score for each candidate, each of the five criteria categories included in Table 3 (excluding the sixth category) was given equal proportional weight (thus weights varied among individual criteria). On the basis of overall evaluation scores averaged across all survey participants, candidate attributes and measures were ranked *within categories* to form a preliminary prioritization of candidate attributes and measures. This ranked list of candidates was the starting point for vital-sign discussions held during the workshop.

Table 3. Vital-sign evaluation criteria used by the NCPN during the pre-workshop evaluation exercise and during the April 2003 vital-signs workshop. Unless noted otherwise, for each candidate vital sign (environmental attribute or measure) participants were instructed to score all criteria from 0-5 where 0 indicated total disagreement with the stated criterion and 1-5 reflected differing degrees of agreement from weak (1) to very strong (5). If interpreted as simple yes-no statement, 0=no and 5=yes.

1. MANAGEMENT SIGNIFICANCE & UTILITY		**Explanatory Comments / Considerations**
1.1	Degree of legislative / policy mandate associated with vital sign.	**Scoring approach:**
		5. Required by Endangered Species Act, Clean Water Act, Clean Air Act (Class 1 airsheds), or park enabling legislation that mentions specific resource.
		4. Specifically covered by an Executive Order (e.g., invasive plants, wetlands) or by a specific Memorandum of Understanding signed by NPS (e.g., bird monitoring).
		3. Vital sign is associated with a resource or issue that is specifically covered by a GPRA goal or some type of federal or state law in addition to the Organic Act and other general legislative mandates and NPS Management Policies.
		2. Vital sign is associated with a resource that is specifically mentioned in park General Management Plan or Resource Management Plan (or similar document).
		1. Vital sign is not covered by any of the specific mandates listed above, but is associated with a resource or issue that is covered by the Organic Act, other general legislative mandates, and/or NPS Management Policies.
		0. Applicable, but none of the above.
		Not applicable: Vital signs associated with natural drivers of resource change and variability or anthropogenic stressors.
1.2	Vital sign is pertinent to one or more specific management concerns.	Overlaps with criterion 1.1, but criterion 1.2 should be scored to reflect degree of management concern independent of any specific mandate. Other considerations pertinent to this criterion: Vital sign should be responsive to one or more stressors affecting park resources. There should be an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management actions. If associated with species-level (or population-level) monitoring, vital sign should be an attribute of a species that is legally protected, endemic, harvested, endemic, alien, or otherwise of special interest or concern. Management concern may be attributable to the fact that the resource has high public appeal.
1.3	Vital sign reliably predicts adverse changes that can be averted by management actions.	For purposes of resource protection and management, a vital sign that predicts adverse changes before they occur (i.e., serves as early warning) is more useful than one that reflects adverse changes only after they have occurred. (Some vital signs may do both.) Likewise, a vital sign that predicts changes that can be averted by management actions is more useful than a vital sign that predicts changes that cannot be averted by management. Ideally, vital signs that indicate resource conditions should be responsive to management actions within a relatively short period of time.

Table 3 continued.

1. MANAGEMENT SIGNIFICANCE & UTILITY		**Explanatory Comments / Considerations**
1.4	Vital sign produces results (data & interpretations) that are easily communicated, easily understood, and accepted by scientists, policy makers, managers, and the general public, all of whom should recognize implications of vital signs results for protecting and managing the park's resources.	Vital signs that are easily communicated and understood may have greater management utility than those that are not.
2. ECOLOGICAL SIGNIFICANCE & SCIENTIFIC VALIDITY		**Explanatory Comments / Considerations**
2.1	Vital sign reliably reflects the status of key ecosystem processes or properties. **OR** if vital sign represents a stressor or natural driver of ecosystem change, then the stressor / driver strongly affects functioning of one or more critical ecosystem processes / properties.	**NOTE:** Replace term *ecosystem* with *landscape, population, or other resource* as appropriate. Relationship between vital sign and associated process or property should be supported by peer-reviewed literature.
2.2	Vital sign reflects the capacity of critical ecosystem processes to resist or recover from change caused by natural disturbances and/or anthropogenic stressors.	**NOTE 1:** Replace term *ecosystem* with *landscape, population* or other *resource* as appropriate. **NOTE 2:** Vital signs that represent anthropogenic stressors or climate should be scored as **Not Applicable**.
2.3	Vital sign is anticipatory -- i.e., reflects an impending change in key components or functions of the ecosystem or other natural resource.	Similar to criterion 1.3, a vital sign that predicts or anticipates impending ecological changes is more useful than a vital sign that reflects ecological changes only after they have occurred.
3. FEASIBILITY & COST OF IMPLEMENTATION		**Explanatory Comments / Considerations**
3.1	Vital sign can be cost-effectively measured.	Consider technical / logistical feasibility, availability of existing methods, and full costs of methods development and implementation (includes training, instrumentation, preparation time, travel & site accessibility, sampling time, sample transport, sample processing & analysis, long-term data management, etc.). Benefits (information value) gained from vital sign should be high relative to total costs incurred. The most cost-effective vital sign is that which indicates the most (in terms of overall resource condition) for the least cost.
3.2	Measurement of vital sign is nondestructive.	Measurement of vital sign should not impact site conditions or protected organisms. Measurement should not affect simultaneous measures of other vital signs or subsequent measures of the same vital sign.
4. RESPONSE VARIABILITY		**Explanatory Comments / Considerations**
4.1	Measurement of vital sign can repeatedly and reliably sort human-caused changes from natural changes over a wide range of resource conditions.	**NOTE: Default answer for natural drivers (e.g., climate) and anthropogenic stressors is YES.** Other considerations: Measurement of vital sign should be repeatable by different observers and by same observer at a different time. Natural and human factors affecting spatial and temporal variability in the vital sign should be well-understood and reliably differentiated. Vital sign should respond to human factors in predictable, unambiguous manner and should be able to discriminate among sites along a known condition gradient. Vital sign should be capable of providing a continuous assessment over a wide range of stress.

Table 3 continued.

5. EXISTING DATA & PROGRAMS		**Explanatory Comments / Considerations**
5.1	Vital sign has been inventoried or is already monitored **within** park (i.e., baseline data are available).	In general, more data are better (e.g., number of years and/or number of stations) -- but the *quality* of existing baseline data also should be considered in relation to this criterion.
5.2	Vital sign is monitored **outside** of park (e.g., by other agencies or regional/national monitoring programs).	In general, more data are better (e.g., number of years and/or number of stations) -- but the *quality* of existing outside data also should be considered in relation to this criterion.
5.3	Data associated with this vital sign are readily available, shared, and/or can be obtained from elsewhere at minimal expense to I&M program.	Some forms of monitoring may be accomplished by acquiring data from other existing sources rather than from new field measurements.
6. PROGRAM INTEGRATION		**Explanatory Comments / Considerations**
6.1	Integrative – the full **SUITE** of vital signs spans key environmental gradients (e.g., soils, elevation, terrestrial > riparian > aquatic), ecological hierarchy (landscapes, ecosystems, populations), spatial scales, and system characteristics / components (including structure, function, and composition).	Applies to full suite of candidate or selected vital signs rather than to individual vital signs.

Vital-Signs Workshop

On 7-9 April 2003, a 2 ½ – day NCPN vital-signs workshop was held in Moab. Purposes of the workshop were (1) to review results of the pre-workshop vital-sign evaluation exercise, and (2) to identify network-level vital-sign priorities on the basis of cross-network commonalities in evaluation results and previously identified program emphases. Participants included NPS staff from parks and the network (including managers and technical staff), USGS and academic cooperators, and NCPN science-panel members. (See Appendix A for a list of participants.) Water quality vital signs, though included in the Delphi and pre-workshop surveys, were addressed separately during a subsequent two-day workshop on 10-11 April 2003 (see below).

During the first half of the workshop, participants discussed average evaluation scores associated with particular measures and evaluation criteria (Table 3). Numerous evaluation scores were revised to reflect group decisions concerning the relative merits of various measures in relation to the evaluation criteria. After the group reached a consensus regarding the evaluation scores assigned to all of the measures and attributes under consideration, relative weighting schemes were discussed. This discussion focused on whether the five criteria categories (Table 4) should receive equal or different weights, and whether individual criteria should be eliminated or emphasized. To develop a final overall ranking of candidate attributes and measures, the group decided to apply the following relative weights to criteria categories:

- Management Significance & Utility – 35%
- Ecological Significance & Scientific Validity – 35%
- Feasibility and Cost of Implementation – 20%
- Response Variability – 10%
- Existing Data and Programs – 0%

No weight was given to the Existing Data and Programs category because the group decided that candidate attributes or measures should not be "penalized" for not having been monitored in the past. Weights were applied to the consensus evaluation scores, and the resulting overall evaluation scores were used to produce a final ranking of candidate attributes and measures. See Appendix Table A-12 for this final result.

During the second half of the workshop, participants discussed and adjusted the rankings that resulted from the process described above. The objective of this discussion was to agree upon network-level vital-sign priorities informed by evaluation results and previously identified program emphases. Given budgetary constraints of the program, it was anticipated that the list of network-level vital-sign priorities would be considerably shorter than the full list of measures under consideration. Nevertheless, very few candidate attributes and measures were dropped from consideration during group discussion. Some candidate measures that previously had been trimmed from the list (e.g., following the second Delphi survey) were reconsidered and added back to the list. (Appendix Table A-5 indicates measures retained after workshop.)

The outcome of the workshop was that the group validated nearly the full list of considered measures as a good set of potential vital signs. However, relative priorities remained ambiguous. Another outcome of the workshop was the evident need to aggregate attributes and measures evaluated during the Delphi and subsequent steps with the intent of identifying vital signs at a more-generalized level of detail. This was the origin of the endpoint-oriented discussion of vital signs reflected above in Figure 1 and below in the remainder of this chapter.

[It is important to note that a variety of alternative approaches to vital-sign evaluation were suggested by different participants during various stages of the workshop process. All of the suggested approaches had merit, but the group decided to proceed with the process as planned because of time constraints. Appendix A briefly addresses this and additional issues that arose during the workshop.]

Post-Workshop Follow-Up and Synthesis

After the April 2003 workshop, the NCPN ecologist engaged in a round of follow-up visits to parks. All NCPN parks were visited during May-June 2003 to identify park-specific monitoring needs and increase network familiarity with park resources and issues. Also during this period, network staff worked closely with the SCPN in developing unified conceptual-modeling approaches (see Appendix I); vital-signs frameworks (Figure 1; Tables 1 and 2); and inventory, assessment and monitoring protocols for springs, seeps, and hanging gardens.

Park visits, coordination with the SCPN, and a reconsideration of input received during various phases of the vital-signs evaluation process facilitated the reorganization of candidate attributes and measures retained after the April workshop. These relatively specific measures were synthesized and aggregated into a shorter list of endpoint-oriented vital-sign candidates that is broadly applicable across the NCPN (Table 4). This list subsequently was reviewed and accepted by park staff, and it served as the foundation for the development by NCPN and park staff of park-specific vital-sign tables presented in the following section. Potential measures associated with these vital signs are presented in Appendix B.

Table 4. Vital signs of broad applicability across the NCPN. List was derived from synthesis and aggregation of candidate measures retained following the April 2003 vital signs workshop (Appendix A). See Appendix B for potential measures associated with individual vital signs.

Vital-Sign Category	VITAL SIGN
Ecosystem characteristics	
Climatic conditions	Precipitation patterns
	Temperature patterns
	Wind patterns
Air quality	Atmospheric deposition
	Visibility
	Tropospheric ozone levels
Soil, water, and nutrient dynamics	Upland soil / site stability
	Upland hydrologic function
	Nutrient cycling
	Stream flow regime
	Stream / wetland hydrologic function
	Groundwater dynamics
Water quality	SEE WATER QUALITY SECTION

Table 4 continued.

Vital-Sign Category		VITAL SIGN
Disturbance regimes		Fire regimes
		Hillslope erosional processes
		Extreme climatic events
		Insect / disease outbreaks in forests and woodlands
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities (particular communities of interest may vary among parks in relation to values, threats, and probability/consequences of change.)
	At-risk species or communities	Status of at-risk species – amphibian populations
		Status of at-risk species – bat populations
		Status of at-risk species – Mexican spotted owl populations
		Status of at-risk species – peregrine falcon populations
		Status of at-risk species – other TES vertebrate populations (spp. vary by park)
		Status of at-risk species – TES plant populations (spp. vary by park)
		Status of at-risk communities – riparian-obligate birds
		Status of at-risk communities – sagebrush-obligate birds
		Status of at-risk communities – pinyon-juniper-obligate birds
		Status of at-risk communities – native fish communities
		Status of at-risk communities – native grassland / meadow plant communities
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities
	At-risk species or communities / Focal species or communities	Status of at-risk / focal communities – riparian / wetland plant communities
	Focal species or communities	Status of focal communities – biological soil crusts
		Status of focal communities – aquatic macroinvertebrates
		Status of focal communities – other aquatic communities (communities vary by park)
	Focal species or communities / Endemic species or unique communities	Status of focal / unique communities – spring, seep, & hanging-garden communities
	Endemic species or unique communities	Status of rare / endemic plant populations (spp. vary by park)
		Status of other unique communities (communities vary by park)
Landscape-level patterns		Land cover
		Land use
		Land condition
		Park insularization
		Landscape fragmentation and connectivity
Other vital-sign categories		
Stressors		Park use by visitors
		Invasive exotic plants
		Invasive, exotic, and/or feral animals
		Occurrence patterns of novel diseases / pathogens
		Permitted consumptive / extractive activities on park lands
		Park administration and operations
		Changes in stream hydrologic regimes due to surface-water diversions
		Changes in stream hydrologic regimes due to large reservoirs
		Changes in groundwater hydrologic regimes due to groundwater extraction
		Adjacent / upstream land-use activities
		Non-compliant uses on park lands
Other natural resource values		Status of paleontological resources
		Status of natural night skies
		Status of natural soundscapes

NCPN Vital Signs (excluding water quality)

This section begins with a network-level overview and discussion of vital signs that have been identified and prioritized for NCPN parks. Following the network-level overview, park-specific vital signs are presented in greater detail. Park-specific discussions emphasize relationships of vital-sign priorities to key park resources and issues. Although existing monitoring data and programs did not contribute to overall vital-sign evaluation scores during the April workshop (see above and Appendix A), these did play a significant role in the assignment of park-specific vital-sign priorities presented below.

Network Overview

Before discussing vital signs selected by NCPN parks, it is important to recognize that an on-going objective of the NCPN has been to frame a monitoring program that identifies critical park monitoring needs for purposes of maintaining and restoring the integrity of park ecosystems. The NCPN from the outset has recognized that base funding associated with the vital-signs monitoring program will be insufficient to meet this comprehensive set of needs. Nevertheless, there is considerable value in identifying an integrative and relatively comprehensive set of vital signs both for strategic purposes and for purposes of facilitating integrated whole-system thinking. It is the vision of the NCPN that vital-signs monitoring ultimately will be accomplished through a variety of funding mechanisms and partnerships. Thus during Phase III it will be important to assess these various funding mechanisms and partnerships for their relative degree of long-term security, and to ensure that the core integrity of the NCPN vital-signs monitoring program is not vulnerable to programmatic changes that occur outside the I&M Program itself.

Consistent with an ecosystem approach to resource stewardship and monitoring, it is also important to recognize that there are many relationships among vital signs discussed below. In all aspects of design, implementation, and analysis, monitoring of particular community- and population-level vital signs will be integrated with monitoring of other pertinent vital signs such as those associated with climate, disturbance regimes, soil/water/nutrient dynamics, landscape patterns, and stressors. Design work conducted during Phase III will emphasize integrated approaches to monitoring *suites* of related vital signs.

Climatic Conditions

Climate is encompassed within the concept of "atmospheric resources and conditions" – one of the four interactive controls of ecosystem sustainability reflected in the Jenny-Chapin model (Chapin et al. 1996). As such, it is an essential component of the NCPN monitoring program. Numerous climatic parameters were evaluated during the vital-sign evaluation process (see Appendix A, Table A-5). Of these, precipitation patterns and air-temperature patterns ranked highest overall in relation to the evaluation criteria (Appendix A, Table A-12). Because of their significance for driving or regulating multiple biotic and abiotic processes, precipitation and air temperature have been identified has high-priority vital signs at all NCPN parks. Wind patterns, which also affect multiple ecological processes (e.g., energy balance, evaporative demand, fire behavior, spatial redistribution of soil resources), have been identified as medium priority relative to other climatic vital signs at all parks and across the network as a whole (Table 5). Because of the significance of extreme climatic events (particularly precipitation and wind) as disturbances affecting ecosystem structure and function (Whitford 2002), climatic monitoring overlaps with disturbance monitoring.

Table 5. Overview of vital signs identified by NCPN parks. Relative priorities within parks and across the NCPN as a whole are indicated by Xs (high xxx, medium xx, low x). Overall network priorities (last column) are based on cross-network commonalities and previously identified program emphases. Tallies at bottom of table are derived from separate park-specific tables. See these tables for additional details pertaining to park vital signs.

Category		VITAL SIGN	ARCH	BLCA	BRCA	CANY	CARE	CEBR	COLM	CURE	DINO	FOBU	GOSP	HOVE	NABR	PISP	TICA	ZION	NCPN Priority
Ecosystem characteristics																			
Climatic conditions		Precipitation patterns	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	**XXX**
		Air temperature patterns	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	**XXX**
		Wind patterns	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	**XX**
Air quality		Atmospheric deposition	XXX	XXX	XXX	XXX	XXX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XXX	**XXX**
		Visibility	XXX	XXX	XXX	XXX	XXX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XXX	**XXX**
		Tropospheric ozone levels	XXX	XXX	XXX	XXX	XXX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XXX	**XXX**
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XX	XXX	XXX	XXX	XX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XX	X	XXX	**XXX**
		Upland hydrologic function	XXX	XX	XXX	XXX	XXX	XX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XX	X	XXX	**XXX**
		Nutrient cycling	XXX	XX	XXX	XXX	XXX	XX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XX	X	XXX	**XXX**
		Stream flow regime	XXX	XXX	X	XXX	XXX		XXX	XXX	XXX	X			XXX		X	XXX	**XXX**
		Stream / wetland hydrologic function	XXX	XXX	X	XXX	XXX	X	XX	XXX	XXX	XXX			X	X	X	XXX	**XXX**
		Groundwater dynamics	XXX		XX	XXX	XXX		X	X	X	XXX		XXX	XXX	XXX		XXX	**XXX**
Water quality		SEE WATER QUALITY TABLES	XXX	XXX	XXX	XXX	XXX	X	XX	XXX	XXX	XX		XXX	XXX	XXX	XXX	XXX	**XXX**
Disturbance regimes		Fire regimes	X	XXX	XXX	X	X	XXX	XXX	XX	XXX	XXX	XXX	XX	XX		XX	XXX	**XXX**
		Hillslope erosional processes			XX			XX											**X**
		Extreme climatic events	XXX	XX	XX	XXX	XXX	XX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	**XXX**
		Insect / disease outbreaks in forests and woodlands	X	X	XX	X	X	XXX	XX	X	X	XX		X	X	X	XX	XX	**XX**
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities (particular communities of interest may vary among parks in relation to values, threats, and probability/consequences of change.)	XXX	XX	XX	XXX	XXX	XXX	XX	XXX	XXX	XXX	XX	XXX	XXX	X	X	XXX	**XXX**
	At-risk species or communities	Status of at-risk species – amphibian populations	X			XX	X		X	X	X				X	X		X	**XX**
		Status of at-risk species – bat populations	XX		X	XX	X	XX	X		X	X		XX	XX	XX	XXX	XX	**XX**
		Status of at-risk species – Mexican spotted owl populations				XXX	XXX				X							XXX	**XXX**
		Status of at-risk species – peregrine falcon populations	X	XX	X	XX	X	X	X	X	XXX				X			XX	
		Status of at-risk species – other TES vertebrate populations (spp. vary by park)		XXX	XXX	XXX				XXX	XXX	XXX						XXX	
		Status of at-risk species – TES plant populations (spp. vary by park)					XXX	XXX			XX							XXX	**XXX**
		Status of at-risk communities – riparian-obligate birds	XXX	XX		XXX	XXX			XX	XXX				XXX	XX		XXX	**XXX**
		Status of at-risk communities – sagebrush-obligate birds		X			XX			XX	X	XX	X	XX		XX			**XX**
		Status of at-risk communities – pinyon-juniper-obligate birds	X	X		X	X		XX		X				XX	XX		XX	
		Status of at-risk communities – native fish communities		X		XXX	XX				XXX							XXX	**XX**
		Status of at-risk communities – native grassland / meadow plant communities			XX	XXX	XXX	XXX			XXX					X		XX	**XXX**
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities		XX					X	XXX	XXX	XXX	XXX	XXX				X	**XXX**
	Focal species or communities	Status of at-risk / focal communities – riparian / wetland plant communities	XXX	XXX	XX	XXX	XXX	XX	XXX	XX	XXX	XX			XXX	X	X	XXX	**XXX**

Table 5 continued.

Category		VITAL SIGN	ARCH	BLCA	BRCA	CANY	CARE	CEBR	COLM	CURE	DINO	FOBU	GOSP	HOVE	NABR	PISP	TICA	ZION	NCPN Priority
Ecosystem characteristics																			
Biotic integrity	Focal species or communities	Status of focal communities – biological soil crusts	XXX	XX		XXX	XX		XXX	XX	XXX	XX		XXX	XXX			XXX	**XXX**
		Status of focal communities – aquatic macroinvertebrates	XXX	XXX	X	XXX	XX			XXX	XX	XX		XXX	XXX			XXX	**XXX**
		Status of focal communities – other aquatic communities (communities vary by park)		X						XX									**X**
		Status of focal / unique communities – spring, seep, & hanging-garden communities	XXX	XX	XXX	XXX	XXX	X	XXX	X	XX	XX		XXX	XXX	X		XXX	**XXX**
	Endemic species or unique communities	Status of rare / endemic plant populations (spp. vary by park)	XXX	X	XX	X	XXX	XX	X	X	XXX	X			XXX			X	**XXX**
		Status of other unique communities (communities vary by park)	XX			XX	X	X	X								XXX	XX	**X**
Landscape-level patterns		Land cover	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	**XXX**
		Land use	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	**XXX**
		Land condition	XX	XX	XX	XX	XXX	XX	XX	XX	XXX	XX	XX	XX	XX	XX		XX	**XX**
		Park insularization	XXX	XXX	XX	XX	XX	XXX	XXX	XXX	XX	XXX	XXX	XXX	XX	XXX	XX	XXX	**XXX**
		Fragmentation and connectivity	XXX	XXX	XX	XX	XX	XXX	XXX	XXX	XX	XXX	XXX	XXX	XX	XXX	XX	XXX	**XXX**
Other vital sign categories																			
Stressors		Park use by visitors	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	**XXX**
		Invasive exotic plants	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	**XXX**
		Invasive, exotic, and/or feral animals	XX	X	X	XXX	X	X	XX	X	XXX	X	X	XX	XX	X	XX	XX	**XX**
		Occurrence patterns of novel diseases / pathogens	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	**X**
		Permitted consumptive / extractive activities on park lands		XX	X		XXX			XX	XXX	XX							**X**
		Park administration and operations	XXX	XX	XX	XXX	X	X	X	XX	X	XX	X	XXX	XXX	X	XX	XX	**XX**
		Changes in stream hydrologic regimes due to surface-water diversions	XX	X	X	X	XX			XX	XX	XXX			X		X	XX	**XX**
		Changes in stream hydrologic regimes due to large reservoirs		XXX		XX				XXX	XXX								**XX**
		Changes in groundwater hydrologic regimes due to groundwater extraction	XXX	X	XX		X		X		X		X	XXX	XXX	XXX		XX	**XX**
		Adjacent / upstream land-use activities	XXX	XXX	XX	XXX	XXX	XX	XXX	XXX	XXX	XX	XXX	XX	XX	XXX	XXX	XXX	**XXX**
		Non-compliant uses on park lands	X	X	X	XXX	XXX	X	X	XX	X			XX	XX			XXX	**XX**
Other natural resource values		Status of paleontological resources	X		XXX	XX	X			X	XX	XXX						X	**X**
		Status of natural night skies	XXX	X	XXX	XXX	XX	X	XX		XX	X	X	XXX	XXX			XX	**XX**
		Status of natural soundscapes	XXX	X	XX	XXX	XX	XX	XX		XX	X	X	XXX	XXX		XXX	XX	**XX**
		Number of high-priority vital signs (see park-specific tables for details)	31	20	18	33	37	13	18	21	31	21	15	23	24	13	18	33	**34**
		Number of high-priority vital signs currently monitored to some degree (see park-specific tables for details)	21	13	9	19	20	3	4	8	14	6	2	10	12	5	10	18	**--**

Air Quality

Like climate, air quality is included in the concept of "atmospheric resources and conditions" in the Jenny-Chapin model. Nitrogen (N) deposition (included in Table 6 in the general vital sign "atmospheric deposition"), particulate concentrations, visibility, and tropospheric ozone concentrations were the air quality parameters that ranked highest overall in relation to evaluation criteria (Table A-12). Nitrogen deposition in particular is a major component of global change, with potential implications for numerous ecological patterns and processes including ecosystem susceptibility to exotic species invasions (Asner et al. 1997, Galloway et al. 2003, Fenn et al. 2003b). Although current rates of N deposition generally are low across most of the western United States, there is very little information available for areas immediately downwind of emissions sources (Fenn et al. 2003a,b). Notably, modeling indicates potential "hot spots" of N deposition in the vicinity of several NCPN units including Zion, Cedar Breaks, Golden Spike, Timpanogos Cave, and Fossil Butte (Fenn et al. 2003a).

Atmospheric deposition, visibility, and tropospheric ozone concentrations have been identified as high-priority vital signs in the six NCPN National Parks (ARCH, BLCA, BRCA, CANY, CARE, and ZION) classified as Class I air-quality areas under the Clean Air Act (Table 5). For purposes of this report, monitoring of particulate concentrations is considered a form of visibility monitoring (Malm 1999). In the remaining NCPN units classified as Class II areas, air quality vital signs have been identified as medium priority relative to other park vital signs. Nearest locations of existing air-quality monitoring stations are indicated in park-specific tables presented later in this report. In all cases, the adequacy of existing air-quality monitoring will be reassessed in relation to park needs as part of the Phase III process.

Soil, Water and Nutrient Dynamics

Soil, water and nutrient dynamics together represent another of the four interactive controls of ecosystem sustainability in the Jenny-Chapin model. During the vital-sign evaluation process, numerous measures associated with upland soil / site stability, upland hydrologic function, and nutrient cycling ranked very high in relation to evaluation criteria (Table A-12). These three closely-related vital signs have been identified elsewhere as important attributes for assessing and monitoring the functional condition of upland ecosystems (e.g., Whisenant 1999, Tongway and Hindley 2000, Whitford 2002, Pyke et al. 2002, Ludwig et al. 2003). The fundamental hypothesis underlying the significance of these vital signs is that sustainability is dependent on maintaining ecosystem capacity for capturing, retaining, and cycling soil and water resources (Whitford 2002). It is anticipated that vital signs in this category will be monitored via a multiscale approach, combining spatially extensive monitoring from aerial platforms with intensive ground-based monitoring at selected locations.

For riparian and aquatic ecosystems, stream flow regime was among the highest ranked of all candidate vital signs considered during the entire evaluation process (Table A-12). The maintenance of natural flow regimes is widely recognized as essential for sustaining the structure and functioning of riparian and aquatic ecosystems (Baron et al. 2002, Naiman et al. 2002, Bunn and Arthington 2002). Stream and wetland hydrologic function – defined here as the capacity of riparian and wetland areas to dissipate flow energies, capture and filter sediment, and retain floodwaters (see Appendix J for full definitions) – also is essential for the integrity of riparian, wetland, and aquatic ecosystems (Prichard et al. 1998, 1999). Because of the importance of groundwater-dependent ecosystems in most NCPN units (e.g., springs, seeps, hanging gardens, intermittent/ephemeral riparian), several measures associated with groundwater dynamics also ranked highly during the vital-sign evaluation process (Table A-12).

All vital signs in this category have been identified as high priority for the network as a whole due to their importance for ecosystem sustainability and their sensitivity to stressors affecting NCPN units (Table 5). The relative priorities of these vital signs within and among parks vary in relation to existing threats and pertinent ecosystems' extent of occurrence.

Water Quality

Water quality is a core component of the NCPN monitoring program. Water quality vital signs have high priority for the network as a whole, though their relative priority within and among parks varies in relation to the abundance and condition of water resources and the existence of threats. Specific water-quality vital signs are identified on a park-by-park basis later in this report.

Disturbance Regimes

Disturbance, another of the four interactive controls of ecosystem sustainability, is a major driver of ecosystem dynamics (Sousa 1984, White and Pickett 1985). Vital signs in this category are associated with the major types of natural disturbances prevalent in NCPN ecosystems. These include extreme climatic events (Allen and Breshears 1998, Whitford 2002), fire (Stein 1988, Allen et al. 2002), and insect / disease outbreaks in forests and woodlands (Logan et al. 2003). Fire occcurrence and insect outbreaks both are strongly related to climatic patterns (Swetnam and Betancourt 1990, 1998; Logan et al. 2003). Hillslope erosion also has been identified as a vital sign in this category due to the widespread significance of this disturbance in the Claron breaks of Bryce Canyon and Cedar Breaks (Table 5). In riparian and aquatic ecosystems, flow events are the prevalent natural disturbances (Goodwin et al. 1997, Bunn and Arthington 2002); in the absence of flow regulation, these also are strongly related to climatic patterns. Human land-use activities have profoundly altered characteristics of upland fire regimes and riparian / aquatic flow regimes throughout much of western North America, with numerous implications for native biodiversity and resource management (Stromberg 2001, Keane et al. 2002, Allen et al. 2002).

Fire regimes and extreme climatic events have been identified as high-priority vital signs for the network as a whole because of their importance in most network parks (Table 5). Relative to these, the vital sign associated with insect / disease outbreaks in forest and woodland ecosystems is of lower priority, primarily because of the prevalance of shrub-dominated ecosystems relative to tree-dominated ecosystems in the NCPN. However, due to strong relationships among all three of these vital signs, NCPN anticipates an integrated approach to monitoring them. The network already is a core participant in the proposed Drought Impacts on Regional Ecosystems Network (DIREnet) that will coordinate research concerning drought effects on ponderosa pine forests and pinyon-juniper woodlands of the Southwest – if funded by the National Science Foundation (see http://denali.cet.nau.edu/SERF/index.php).

Priorities of these vital signs within and among parks vary in relation to the relative significance of these types of disturbances and, in the case of insect / disease outbreaks, the relative extent of tree-dominated ecosystems.

[Flow regime is not explicitly identified as a vital sign associated with disturbance regimes because it is included above under soil, water, and nutrient dynamics.]

Biotic Integrity – Predominant Plant Communities

Chapin and colleagues (1996) describe biotic *functional groups* as one of the four interactive controls of ecosystem sustainability because of the capacity of dominant functional groups to shape the structure and functioning of whole ecosystems. Associated with efforts to model ecological consequences of global change, a vast literature has developed concerning different approaches to deriving or classifying functional groups – particularly with respect to vegetation (e.g., Smith et al. 1997, Díaz and Cabido 2001). At a more general level, vegetation itself is generally recognized as *the* dominant functional group in terrestrial and riparian / wetland ecosystems because of its central role in primary production, nutrient and hydrologic cycles (integrating above- and below-ground processes), earth-atmosphere interactions, disturbance regimes, and in the provision of resources and habitat structure for wildlife at multiple scales.

Although several specific types of plant communities have been identified for emphasis as vital signs on the basis of diversity, degree of peril, and/or distinctiveness (Table 5 and discussion below), the intent of this category is to identify *predominant* plant communities as important elements of biotic integrity because of their functional dominance within ecosystems and across landscapes. Operationally, the concept of predominant plant communities is interpreted to mean common or spatially extensive upland plant communities that may not be particularly unique, diverse or imperiled on a regional basis but are nonetheless important for purposes of sustaining or restoring the integrity of park ecosystems and landscapes. Relative to specific communities of emphasis identified in other vital-sign categories, predominant plant communities may be monitored at lower levels of intensity (i.e., coarser spatial and temporal resolution) or with different measures. As indicated previously, the ecosystem approach adopted by the NCPN requires that monitoring of community-level vital signs will be integrated with monitoring of other pertinent vital signs such as those associated with climate, disturbance regimes, soil/water/nutrient dynamics, landscape patterns, and stressors.

For the network as a whole, the status of predominant plant communities is a high-priority vital sign because of its importance to most network parks, its functional significance generally, and because plant community data are applicable to several other vital signs. During the evaluation process, many measures associated with plant community monitoring ranked very high both as direct measures of plant communities themselves *and* as indirect measures (i.e, indicators) of other important ecosystem attributes (Tables A-12 and B-1). The relative priority of this vital sign within and among parks varies in relation to existing threats, park management issues, and current plant community monitoring.

This vital sign overlaps with many others, including upland soil / site stability, upland hydrologic function, nutrient cycling, fire regimes, insect / disease outbreaks in forests and woodlands, land-cover patterns, land-condition patterns, and invasive exotic plants.

Biotic Integrity – At-Risk Species or Communities

At-risk species. Because of legal mandates or other management concerns, monitoring the status of at-risk species is a high-priority for the network as a whole (Table 5). Although the identity of at-risk species varies considerably from park to park, several species or groups of species are sufficiently widespread to emphasize at the network level.

- Mexican spotted owls (*Strix occidentalis lucida*), which are listed as threatened under the auspices of the Endangered Species Act (ESA), are found in several network parks. Breeding populations in Canyonlands, Capitol Reef, and Zion may be particularly important as source populations for surrounding areas.

- Peregrine falcons (*Falco peregrinus anatum*), which recently have been delisted, also are found in several network parks. From the onset of recovery efforts in the mid-1970s, Dinosaur NM played a central role in recovery of the species due to its strong participation in the recovery program and the high number of known breeding territories in the area. In addition to Dinosaur, peregrines are monitored in several other network parks, and the network as a whole would like to support a continued role for NCPN units during the five-year, post-delisting monitoring period.

- Amphibian populations have been reported as declining or experiencing high frequencies of disease and malformations in numerous locations worldwide (Alford and Richards 1999). Although no network park has identified amphibian monitoring as a high priority at the park level, the network as a whole would like to support NPS participation in the Department of Interior's Amphibian Research and Monitoring Initiative (ARMI) – a program oriented towards determining factors causing reported impacts to amphibian populations. USGS funding has been used to support protocol-development work for amphibian monitoring at Canyonlands as a component of ARMI and the prototype program. Because no amphibian populations in NCPN parks are currently listed as threatened or endangered, amphibian monitoring has been assigned a lower priority than monitoring of listed species.

- Bat populations also have been reported as experiencing widespread declines, although a clear understanding of trends in particular populations usually is hampered by an absence of monitoring data (O'Shea and Bogan 2000, O'Shea et al. 2003). According to the U.S. Fish and Wildlife Service (http://endangered.fws.gov/bats/bats.htm), 26 of 45 bat species found in the continental United States are federally listed as endangered under the ESA (6 spp.) or are identified as species of special concern by the agency. Many of the remaining species also appear to be declining in number – especially cave-dwelling species. Timpanogos Cave NM has identified the status of bat populations as a high-priority vital sign because of suspected declines in cave-dwelling species. There is widespread management concern regarding bats among many other network parks, but no monitoring data exist. As with amphibians, the network as a whole has identified bat population status as a vital sign, but has assigned it a lower priority than monitoring of currently listed taxa.

- Numerous other at-risk taxa occur in NCPN parks. These are identified in subsequent park-specific tables. All are high-priority monitoring needs for the network.

At-risk communities. Several different types of biotic communities will be emphasized in the NCPN monitoring program because they have been described as imperiled on a regional basis. Consistent with servicewide goals for vital-signs monitoring, the network as a whole would like to participate in regional and national monitoring initiatives associated with these resources – with the NCPN providing data on reference conditions as appropriate.

- Plant communities – Of systems found in NCPN units, native grassland / meadow communities, sagebrush steppe communities, and riparian / wetland plant communities have been identified as imperiled on a regional or nationwide basis due to land-use impacts (Noss et al. 1995, Christensen et al. 1996). (Riparian / wetland plant communities in this category are those associated with lotic systems – rivers, perennial streams, and intermittent streams.) The network has assigned high priority to the status of these three types of communities (Table 5). Relative priorities of these vary within and among individual parks depending on the extent of their occurrence.

- Bird communities –Partners in Flight (PIF) is an international program oriented toward documenting and reversing apparent declines of avian populations. The program emphasizes Neotropical migratory birds but considers the status of other species as well. Utah PIF (a component of the international program) has identified "priority" bird species for Utah that are most in need of conservation (Parrish et al. 2002). On the basis of this priority species list, habitat preferences of priority species, and the prevalence of preferred habitats in NCPN units, the network has identified three types of bird communities for emphasis in the monitoring program – riparian obligate birds, sagebrush-obligate birds, and pinyon-juniper-obligate birds (Table 5). Of these, only riparian-obligate birds have been assigned high priority due to existing monitoring efforts and the overall significance of riparian ecosystems in NCPN units.

- Fish communities – Over 60 percent of freshwater fishes in Utah are considered at risk of extinction due to rarity or other factors (Stein 2002). The status of native fish communities is a high priority vital sign for Canyonlands, Zion, and Dinosaur NM, but community-level fish monitoring is a lower priority for the network as a whole.

Biotic Integrity – Focal Species or Communities

Focal species. Because of their functional importance in ecosystems, focal species (defined above and in Appendix J) can play a significant role in monitoring programs (Noon 2003) and in ecosystem management generally (Dale et al. 2002). During scoping, the NCPN has not identified any focal species for emphasis in the monitoring program.

Focal communities. Focal communities are defined as those that play significant functional roles in systems by their disproportionate contribution to the transfer of matter and energy, or by their disproportionate contribution to biodiversity. Through scoping and literature review, the NCPN has identified several focal communities that will be emphasized in the monitoring program.

- Riparian / wetland plant communities – Because of their importance for hydrologic functioning and biodiversity, riparian / wetland plant communities have been identified as focal communities by NCPN. (As above, riparian / wetland plant communities in this category are those associated with rivers, perennial streams, and intermittent streams.) This designation takes on particular significance since these communities also have been identified as at-risk communities. As indicated above, the status of riparian / wetland plant communities is a high-priority vital sign for the network as a whole (Table 5).

- Biological soil crust communities – Because of their contributions to soil / site stability, upland hydrologic functioning, nutrient cycling, and biodiversity (Jones et al. 1994, Belnap and Lange 2001, Belnap 2003), biological soil crust communities have been identified as focal communities by the NCPN. The status of biological soil crust communities is a high-priority vital sign for the network as a whole.

- Aquatic macroinvertebrate communities – Because of their utility as an integrated indicator of water quality and the condition of aquatic ecosystems (Allan 1995, Karr and Chu 1999), aquatic macroinvertebrates have been identified by the NCPN as a focal component of aquatic ecosystems. The status of aquatic macroinvertebrate communities is a high-priority vital sign for the network as a whole. Additional components of aquatic ecosystems have been identified as focal communities by Black Canyon of the Gunnison NP and Curecanti NRA.

- Spring, seep and hanging-garden communities – Like riparian / wetland plant communities, spring, seep and hanging-garden communities have been identified as focal communities by the NCPN because of their disproportionate contribution to landscape-level biodiversity. The status of these communities is a high-priority vital-sign for several network parks as well as for the network as a whole (Table 5). As indicated elsewhere in this report, the ecosystem approach of the NCPN requires that community-level monitoring be integrated with monitoring of other pertinent vital signs such as climate, hydrology, water quality, and stressors.

Biotic Integrity – Endemic Species or Unique Communities

Endemic species. The Colorado Plateau is well known as a center of plant endemism, most of which is correlated with the exposure of raw geologic substrates or unweathered colluvium (Welsh 1978, 1979; Welsh et al. 1993). This high frequency of edaphic endemism is well-represented in NCPN parks. Dinosaur NM and Capitol Reef NM both support more than 40 rare / endemic vascular plant taxa. Other network parks also support impressive numbers of edaphic endemics, particularly Bryce Canyon NP and Cedar Breaks NM where most endemics are associated with limestone breaks of the Claron Formation. The network has identified the status of rare / endemic plant populations as a high-priority vital sign due to the great importance of these resources to network parks (Table 5).

Unique communities. The status of hanging-garden communities (ecosystems) is a high-priority vital sign for the network as a whole. These unique ecosystems are diverse, they support a variety of endemic or obligate taxa, and they are sensitive to several anthropogenic stressors affecting NCPN parks (Welsh and Toft 1981, Welsh 1989, Spence and Henderson 1993).

Because of their contribution to biodiversity, these systems also have been identified as focal systems for the NCPN program (above). The relative priority of this vital sign within and among parks varies depending on the extent of their occurrence. In addition to this unique but relatively widespread community type, individual parks have identified other unique communities as park-specific vital signs (see park-specific tables).

Landscape-Level Patterns

Vital signs included in this category (Tables 4 and 5) are related to many of the ecosystem- and community-level vital signs discussed above, but this category emphasizes broader spatial scales and landscape-level spatial relationships. Two assumptions underlie this category: (1) spatial scale and spatial structure matter in terms of our ability to understand and manage ecosystems (Wiens et al. 2002), and (2) our understanding and management of park ecosystems can be improved by looking beyond park boundaries. Individual vital signs included in this category are closely related; the order in which they are presented in Table 5 generally represents a sequence of increasing analytical detail. (Sample measures presented in Appendix Table B-1 may assist the reader in differentiating among these closely related vital signs.)

Land cover and land use both are high-priority vital signs for all network parks and for the network as a whole because of their importance for providing broad-scale overviews of ecosystem structure and status within and surrounding parks. Land-use and land-cover change are widely recognized as key components of environmental change at local to global scales, with potential impacts on a multitude of ecological patterns and processes (Vitousek 1994, Vitousek et al. 1997, Sala et al. 2000). Both of these were ranked very highly in relation to criteria considered during the evaluation process (Table A-12).

As a landscape-level attribute, land condition is a vital sign which requires spatially extensive assessment and monitoring of ecosystem conditions in relation to desired benchmark conditions (best accomplished with integrated ground- and remotely-based sampling). This is a high-priority vital sign for Capitol Reef NP and Dinosaur NM – the two network parks with the most extensive occurrence of permitted livestock grazing.

Ecological boundaries (or edges) are key components of landscape structure that can strongly affect movements of organisms, materials (e.g., soil and water resources), and disturbances across landscapes (Forman 1995, Aronson and Le Floc'h 1996, Wiens et al. 2002). For purposes of restoring or maintaining the integrity of park ecosystems, it is important to understand the degree to which park boundaries function as ecological boundaries. These concepts are incorporated in the landscape-level vital sign described as “park insularization” (Table 5). As applied here, park insularization refers to the degree of cross-boundary contrast in particular measures of ecosystem status. Effects of cross-boundary contrasts on ecological conditions within parks can vary in relation to park size and shape (Janzen 1983) as reflected in perimeter:area ratios (see Table 20, Evenden et al. 2002). Park insularization has been identified as an important vital sign for all network parks. It is a high-priority monitoring need for those parks characterized by high perimeter:area ratios or by significant interface issues with urban or other private lands. For the network as a whole, this is a high-priority vital sign. Degree of cross-boundary contrast was one of the highest-rated landscape-level measures considered during the evaluation process (Appendix Table A-12).

The inverse concepts of landscape fragmentation and connectivity together represent another landscape-level vital sign (Table 5). Whereas park insularization focuses specifically on park boundaries, landscape fragmentation and connectivity emphasize the size and spatial configuration of ecosystem patches within parks and surrounding landscapes. Fragmentation – the conversion of continuous ecosystem patches into smaller discontinuous patches – has profound impacts on a wide variety of biotic and abiotic processes (Saunders et al. 1991, Turner et al. 2001, Sisk and Haddad 2002). This vital sign has been identified as important for all network parks. Like park insularization, it is a high-priority monitoring need for those parks characterized by high perimeter:area ratios or by significant interface issues with urban or other private lands. For the network as a whole, this is a high-priority vital sign.

Vital signs included in this landscape-pattern category overlap with the concept of stressor-oriented monitoring, which is the focus of the next category.

Stressors

Vital signs in this category are oriented towards pro-active monitoring of predominant anthropogenic factors affecting park ecosystems. Measures associated with pro-active stressor monitoring were among the highest ranking of all candidates considered during the evaluation process (Table A-12). Detection and documentation of cause-and-effect relationships will be unlikely (if not impossible) in the absence of stressor-oriented monitoring. Such cause-and-effect information is necessary to support management decisions, develop mitigation measures, and avoid restoration costs or irreparable resource loss.

Park use by visitors is a high-priority vital sign for all network parks and a high priority for the network as a whole (Table 5). Visitor-use levels are a common concern among all network parks, although visitor-use patterns (in terms of spatial distribution, temporal distribution, and type of activity) vary considerably within and among parks. Potential impacts associated with visitor-use activities are wide-ranging, and can include trampling effects on soils and vegetation (Cole 1990), behavioural disturbances to wildlife (Swarthout and Steidl 2001), and trampling effects on aquatic resources (Shakarjian and Stanford 1998). During Phase III, it is anticipated that visitor-use monitoring with be integrated with effects-oriented monitoring to increase the likelihood of detecting causal relationships. In many cases, visitor-use information gathered at entrance stations or visitors centers will be insufficient to meet site-specific needs associated with documentation of cause-and-effect relationships.

The status of invasive exotic plants is another high-priority vital sign for all network parks and for the network as a whole (Table 5). Exotic plants can can alter community structure via competitive effects on native species, but the most serious threat to native biodiversity comes from exotic species that significantly alter disturbance regimes or soil-resource regimes – two of the interactive controls of ecosystem sustainability (Vitousek 1990; Chapin et al. 1996, 1997). Very early during the scoping process, NCPN parks uniformly expressed a high degree of concern regarding the pervasive effects of invasive exotic plants. Given the ecosystem approach adopted by the NCPN and the need for an ecosystem perspective in exotic species management (Hobbs and Humphries 1995), it is anticipated that invasive plant monitoring will be integrated with ecosystem- and community-level vital signs described above.

The status of invasive, exotic and/or feral animals also has been identified as a stressor-oriented vital sign for the NCPN. Although this vital sign is a lower priority relative to invasive plants, it may be possible to integrate invasive animal monitoring with monitoring of other vital signs. For example, the distribution and abundance of brown-headed cowbirds can be monitored in conjunction with the diversity and abundance of riparian-obligate bird species (a vital sign in the at-risk category). In *The State of the Nation's Ecosystems* (H. John Heinz III Center 2002), the status of invasive bird populations was identified as an important ecological indicator pertinent to the condition of grassland and shrubland ecosystems. The status of exotic animals is a high-priority vital sign for Canyonlands and Dinosaur due to potential impacts of nonnative fish on endangered fish populations found in those parks.

Occurrence patterns of novel pathogens and diseases (often referred to as "emerging infectious diseases" or EIDs, Daszak et al. 1999, 2000) is a vital sign for all network parks and the network as a whole, although it is a lower priority than the status of invasive plants and invasive animals (Table 5). "Novel" or "emerging" diseases are "...diseases that are newly recognized, newly appeared in the population, or are rapidly increasing in incidence or geographic range" (Daszak et al. 2000:446). Examples include West Nile virus, chronic wasting disease, and ranaviral disease. Although a wide variety of factors may be responsible for EIDs, global biotic exchange (i.e., through travel and trade) and global climate change (enabling expansions of geographic ranges) have been suggested as important causes (Daszak et al. 2000). EIDs of wildlife have been described as threats to biodiversity on a global scale (Daszak et al. 2000), and they have been proposed as contributors to global declines in amphibian populations (Daszak et al. 1999). Meyerson and colleagues (2003) recently suggested that EIDs could be used as agents of bioterrorism. Occurrence patterns of novel pathogens and diseases of plants (e.g., sudden oak death) also are included in this vital sign. NCPN does not anticipate field-based monitoring of this vital sign, but rather monitoring by participation in information-sharing networks designed for surveillance purposes. For example, the U.S. Geological Survey's National Wildlife Health Center maintains a website with information on wildlife diseases, including disease surveillance maps (http://wildlifedisease.nbii.gov/).

The status of permitted consumptive or extractive activities on park lands is a vital sign for those parks that currently have permitted livestock grazing or trailing (Table 5). This is a high-priority vital sign for Capitol Reef NP and Dinosaur NM – the two parks where permitted grazing is most extensive. Except for pH as a measure of water quality, measures of permitted livestock use (location, timing, duration, and intensity of use) were the highest ranked of all candidate vital signs considered during the evaluation process (Table A-12). (Reminder: Appendix B presents potential measures associated with this and other vital signs.)

In recognition of the fact that management-related activities can affect the condition of park ecosystems, park administration and operation has been identified as a vital sign for all parks. Ecological impacts of park operations was an issue that was raised repeatedly during various phases of park scoping. During the vital-sign evaluation process, several measures associated with park operations were ranked high in relation to evaluation criteria (Table A-12). Sample measures include the location, timing, and type of weed-control activities and maintenance activities (Table B-1).

Three vital signs oriented toward pro-active monitoring of factors responsible for altered stream and groundwater hydrologic regimes have been identified (Table 5). These are high-priority vital signs for those parks most affected by such factors. Monitoring of these vital signs will be integrated with effects-oriented monitoring of hydrologic regimes and associated plant communities.

Status of adjacent / upstream (and upwind) land-use activities is a high-priority vital sign for most network parks and for the network as a whole (Table 5). This vital sign obviously is related to land-use (described above), but monitoring of land-use activities requires more information than monitoring land-use alone. For example, *agriculture* is a particular type of land-use, but *pesticide application* is an associated land-use activity with attributes pertaining to the type, amount, and timing of application.

The last vital sign identified in this category is the status of non-compliant uses on park lands (Tables 4 and 5). Examples of non-compliant uses include trespass livestock grazing, resource theft, and poaching (Table B-1). This is a high-priority vital sign for Canyonlands NP and Zion NP, but is medium priority for the network as a whole.

Other Natural Resource Values

Network parks have identified three vital signs that pertain to natural-resource values that fall outside the scope of the ecosystem-oriented framework presented above (Tables 4 and 5). The status of paleontological resources is a high-priority vital sign for Bryce Canyon NP and Fossil Butte NM, although it is a lower priority for other parks and the network as a whole. Several parks also have identified the status of natural night skies and natural soundscapes as high-priority vital signs. At Timpanogos Cave, the concern regarding soundscapes pertains to potential impacts of cave tours on acoustic conditions experienced by bats. Both of these vital signs are medium priority for the network as a whole.

Park-Specific Vital Signs

This section presents tables of vital signs identified for individual parks, excluding specific water-quality attributes that are presented in a subsequent section. Narratives accompanying park tables emphasize high-priority vital signs as well as unique vital signs that were not addressed specifically in the network-level overview. Material presented in the preceding network-level overview provides additional context and rationale that supplement these park-specific discussions. The number of high-priority vital signs identified by individual parks generally reflects the diversity of resources and complexity of resource-management concerns associated with the park.

Arches National Park

Arches National Park has identified 31 high-priority vital signs (Table 6). Of these, 21 currently are monitored to one degree or another. In all cases, existing monitoring will be reevaluated in relation to vital-signs needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Arches because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network. Wind patterns, which also affect multiple ecological processes (e.g., energy balance, evaporative demand, fire behavior, spatial redistribution of soil resources), are a lower-priority monitoring need.

Table 6. Vital signs for Arches National Park (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Arches and across the NCPN as a whole. Vital signs that are currently monitored are indicated by “Yes” or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

<table>
<tr><th rowspan="2" colspan="2">Category</th><th rowspan="2">VITAL SIGN</th><th colspan="2">Priority</th><th rowspan="2">Currently Monitored?</th></tr>
<tr><th>ARCH</th><th>NCPN</th></tr>
<tr><td colspan="6">Ecosystem characteristics</td></tr>
<tr><td rowspan="3" colspan="2">Climatic conditions</td><td>Precipitation patterns</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Air temperature patterns</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Wind patterns</td><td>XX</td><td>XX</td><td></td></tr>
<tr><td rowspan="3" colspan="2">Air quality</td><td>Atmospheric deposition</td><td>XXX</td><td>XXX</td><td>CANY</td></tr>
<tr><td>Visibility</td><td>XXX</td><td>XXX</td><td>CANY</td></tr>
<tr><td>Tropospheric ozone levels</td><td>XXX</td><td>XXX</td><td>CANY</td></tr>
<tr><td rowspan="6" colspan="2">Soil, water, and nutrient dynamics</td><td>Upland soil / site stability</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Upland hydrologic function</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Nutrient cycling</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Stream flow regime</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Stream / wetland hydrologic function</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Groundwater dynamics</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td colspan="2">Water quality</td><td>SEE WATER QUALITY TABLE 23</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td rowspan="3" colspan="2">Disturbance regimes</td><td>Fire regimes</td><td>X</td><td>XXX</td><td></td></tr>
<tr><td>Extreme climatic events</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Insect / disease outbreaks in forests and woodlands</td><td>X</td><td>XX</td><td></td></tr>
<tr><td rowspan="19">Biotic integrity</td><td>Predominant plant communities</td><td>Status of predominant upland plant communities</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td rowspan="13">At-risk species or communities</td><td>Status of at-risk species – amphibian populations</td><td>X</td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk species – bat populations</td><td>XX</td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk species – Mexican spotted owl populations</td><td></td><td rowspan="3">XXX</td><td></td></tr>
<tr><td>Status of at-risk species – peregrine falcon populations</td><td>X</td><td>Yes</td></tr>
<tr><td>Status of at-risk species – other TES vertebrate populations (spp. vary by park)</td><td></td><td></td></tr>
<tr><td>Status of at-risk species – TES plant populations (spp. vary by park)</td><td></td><td>XXX</td><td></td></tr>
<tr><td>Status of at-risk communities – riparian-obligate birds</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Status of at-risk communities – sagebrush-obligate birds</td><td></td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk communities – pinyon-juniper-obligate birds</td><td>X</td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk communities – native fish communities</td><td></td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk communities – native grassland / meadow plant communities</td><td></td><td>XXX</td><td></td></tr>
<tr><td>Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities</td><td></td><td>XXX</td><td></td></tr>
<tr><td>Status of at-risk / focal communities – riparian / wetland plant communities</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td rowspan="3">Focal species or communities</td><td>Status of focal communities – biological soil crusts</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Status of focal communities – aquatic macroinvertebrates</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Status of focal / unique communities – spring, seep, & hanging-garden communities</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td rowspan="2">Endemic species or unique communities</td><td>Status of rare / endemic plant populations – Lomatium latilobum (Canyonlands desert parsley)</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Status of unique communities – tinaja / waterpocket communities</td><td>XX</td><td>X</td><td></td></tr>
</table>

Table 6 continued.

Category	VITAL SIGN	Priority		Currently Monitored?
		ARCH	NCPN	
Ecosystem characteristics				
Landscape-level patterns	Land cover	XXX	XXX	
	Land use	XXX	XXX	
	Land condition	XX	XX	
	Park insularization	XXX	XXX	
	Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories				
Stressors	Park use by visitors	XXX	XXX	Yes
	Invasive exotic plants	XXX	XXX	
	Invasive, exotic, and/or feral animals	XX	XX	
	Occurrence patterns of novel diseases / pathogens	X	X	
	Permitted consumptive / extractive activities on park lands		X	
	Park administration and operations	XXX	XX	
	Changes in stream hydrologic regimes due to surface-water diversions	XX	XX	
	Changes in stream hydrologic regimes due to large reservoirs		XX	
	Changes in groundwater hydrologic regimes due to groundwater extraction	XXX	XX	
	Adjacent / upstream land-use activities	XXX	XXX	
	Non-compliant uses on park lands	X	XX	
Other natural resource values	Status of paleontological resources	X	X	
	Status of natural night skies	XXX	XX	Yes
	Status of natural soundscapes	XXX	XX	Yes

Air quality. Arches is classified as a Class I area under the Clean Air Act. As a consequence, all vital signs related to air quality are high priority. These currently are monitored nearby at the Island in the Sky district of Canyonlands National Park.

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Arches because of their significance for the sustainability of upland ecosystems and because of their sensitivity to visitor-use impacts. Measures associated with these closely related vital signs currently are monitored in conjunction with the VERP (Visitor Experience and Resource Protection) program (Belnap 1998).

Stream hydrologic function is a high-priority vital sign for Arches because of its significance for the sustainability of riparian ecosystems (Courthouse Wash) and because of potential impacts from visitor-use activities. This vital sign currently is being monitored with repeat photography and repeated measures of channel morphology. Stream flow also is a high-priority vital sign; currently this is monitored qualitatively in conjunction with water-quality monitoring (see water-quality section).

Because of the abundance of groundwater-dependent springs, seeps, and hanging gardens (focal ecosystems), and the potential for impacts associated with adjacent development activities, groundwater dynamics is a high-priority vital sign for Arches.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Arches. See the water-quality discussion (below) for details.

Disturbance regimes. Extreme climatic events are the predominant natural disturbances at Arches. Because of the importance of climatic events as drivers of ecosystem variability and change, this is a high-priority vital sign for Arches.

Biotic integrity. Continued monitoring of predominant upland plant communities and riparian / wetland plant communities is a high priority for Arches. The current emphasis of vegetation monitoring at Arches is to assess dynamics of plant communities in relation to climatic fluctuations and natural disturbances (see summary of existing monitoring in Phase I report). The status of riparian-obligate bird communities currently is monitored at Arches, and continued monitoring is a high priority in coordination with regional-level bird-monitoring efforts (see discussion in network-level overview). The status of biological soil crust communities and aquatic macroinvertebrate communities (focal communities) are high-priority vital signs for Arches because of their functional significance for upland and aquatic ecosystems, respectively. Springs, seeps, and hanging gardens – focal ecosystems emphasized in the network program – are abundant at Arches. The condition of these ecosystems is a high-priority vital sign that is not currently monitored at Arches. The status of *Lomatium latilobum* populations (a rare endemic plant) also is a high-priority vital sign for Arches. The status of bat populations and unique tinaja communities / ecosystems also are important vital signs for Arches.

Landscape-level patterns. Land use and land cover– particularly adjacent to Arches – are both high-priority vital signs because of the potential for these to impact park resources via a wide variety of ecological mechanisms. Similarly, degree of park insularization, and landscape fragmentation and connectivity are high-priority vital signs for the park due to existing land-use activities and future potential development on adjacent lands. The status of land-condition patterns surrounding the park also is an important vital sign for Arches.

Stressors. Five vital-signs associated with pro-active monitoring of anthropogenic stressors are high-priority monitoring needs for Arches. These include park use by visitors, invasive exotic plants, park administration / operations, groundwater extraction, and adjacent and/or upstream land-use activities. Total park visitation currently is monitored, but additional data concerning spatial and temporal patterns of visitor-use activities may be required to supplement other vital-signs monitoring. Two other important stressor-oriented vital signs are the status of invasive, exotic, and/or feral animals, and changes in hydrologic regimes due to surface-water diversions.

Other natural resource values. The status of natural night skies and natural soundscapes also are high-priority vital signs for Arches due to encroaching development. Baseline data documenting existing night-sky conditions currently are being collected.

Black Canyon of the Gunnison National Park

Black Canyon of the Gunnison National Park has identified 20 high-priority vital signs (Table 7). Of these, 13 currently are monitored to one degree or another. In all cases, existing monitoring will be reevaluated in relation to vital-signs needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Black Canyon because of their significance as drivers of ecosystem variability and change. Precipitation, temperature, and wind patterns currently are monitored via automated RAWS (remote area weather station) fire-weather stations.

Table 7. Vital signs for Black Canyon of the Gunnison National Park (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Black Canyon and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority		Currently Monitored?
			BLCA	NCPN	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
		Air temperature patterns	XXX	XXX	Yes
		Wind patterns	XX	XX	Yes
Air quality		Atmospheric deposition	XXX	XXX	Gothic, CO (70 km NE)
		Visibility	XXX	XXX	Weminuche Wilderness Area (100 km S)
		Tropospheric ozone levels	XXX	XXX	BLCA (passive)
Soil, water, and nutrient dynamics		Upland soil / site stability	XX	XXX	
		Upland hydrologic function	XX	XXX	
		Nutrient cycling	XX	XXX	
		Stream flow regime	XXX	XXX	Yes
		Stream / wetland hydrologic function	XXX	XXX	Yes
		Groundwater dynamics		XXX	
Water quality		SEE WATER QUALITY TABLE 24	XXX	XXX	Yes
Disturbance regimes		Fire regimes	XXX	XXX	Yes
		Extreme climatic events	XX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	X	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XX	XXX	
	At-risk species or communities	Status of at-risk species – amphibian populations		XX	
		Status of at-risk species – bat populations		XX	
		Status of at-risk species – Mexican spotted owl populations			
		Status of at-risk species – peregrine falcon populations	XX	XXX	Yes
		Status of at-risk species – Gunnison sagegrouse populations	XXX		Yes
		Status of at-risk species – TES plant populations (spp. vary by park)		XXX	
		Status of at-risk communities – riparian-obligate birds	XX	XXX	Yes
		Status of at-risk communities – sagebrush-obligate birds	X	XX	
		Status of at-risk communities – pinyon-juniper-obligate birds	X	XX	
		Status of at-risk communities – native fish communities	X	XX	
		Status of at-risk communities – native grassland / meadow plant communities		XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities	XX	XXX	
		Status of at-risk / focal communities – riparian / wetland plant communities	XXX	XXX	Yes
	Focal species or communities	Status of focal communities – biological soil crusts	XX	XXX	
		Status of focal communities – aquatic macroinvertebrates	XXX	XXX	Yes
		Status of focal communities – aquatic macrophyte communities	X	X	
		Status of focal communities – riverine algal communities	X	X	
		Status of focal / unique communities – spring, seep, & hanging-garden communities	XX	XXX	
	Endemic species or unique communities	Status of rare / endemic plant populations – *Gilia penstemoides*, *Sullivantia hapemanii* var. *purpusii*	X	XXX	
		Status of other unique communities (communities vary by park)		X	

Table 7 continued.

Category	VITAL SIGN	Priority		Currently Monitored?
		BLCA	NCPN	
Ecosystem characteristics				
Landscape-level patterns	Land cover	XXX	XXX	
	Land use	XXX	XXX	
	Land condition	XX	XX	
	Park insularization	XXX	XXX	
	Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories				
Stressors	Park use by visitors	XXX	XXX	Yes
	Invasive exotic plants	XXX	XXX	
	Invasive, exotic, and/or feral animals	X	XX	
	Occurrence patterns of novel diseases / pathogens	X	X	
	Permitted consumptive / extractive activities on park lands	XX	X	
	Park administration and operations	XX	XX	
	Changes in stream hydrologic regimes due to surface-water diversions	X	XX	
	Changes in stream hydrologic regimes due to large reservoirs	XXX	XX	
	Changes in groundwater hydrologic regimes due to groundwater extraction	X	XX	
	Adjacent / upstream land-use activities	XXX	XXX	
	Non-compliant uses on park lands	X	XX	
Other natural resource values	Status of paleontological resources		X	
	Status of natural night skies	X	XX	
	Status of natural soundscapes	X	XX	

Air quality. Black Canyon is classified as a Class I area under the Clean Air Act. As a consequence, all vital signs related to air quality are high priority. Atmospheric ozone (passive, during summer) is the only air-quality vital sign that is monitored at Black Canyon. Atmospheric deposition and airborne particulate levels (visibility measure) are monitored 70-100 km away. The adequacy of this monitoring for Black Canyon will be assessed during the Phase III process.

Soil, water, and nutrient dynamics. Stream flow regime and stream hydrologic function both are high-priority vital signs for Black Canyon because of their significance for the sustainability of the park's key resources – the riparian and aquatic ecosystems of the Gunnison River. Upland soil / site stability, hydrologic function, and nutrient cycling also have been identified as vital signs for Black Canyon, but these are of lower priority relative to stream flow and hydrologic function.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Black Canyon. See the water-quality discussion (below) for details.

Disturbance regimes. Other than stream-flow events (which are captured under flow regime, above), wildfire is the predominant natural disturbance at Black Canyon. As a consequence, the status of fire regimes is a high-priority vital sign for the park. Disturbance associated with extreme climatic events also is an important vital sign for Black Canyon.

Biotic integrity. The status of two focal communities – riparian vegetation and aquatic macroinvertebrates – are high-priority monitoring needs for Black Canyon. The status of upland plant communities also is a vital sign for the park, but this is a lower priority relative to riparian communities. Because of their functional significance for aquatic ecosystems (Allan 1995), Black Canyon has identified aquatic macrophyte and and riverine algal communities of the Gunnison River as vital signs; these are lower priority than riparian plant communities.

The status of Gunnison sagegrouse populations (candidate for federal listing) is a high-priority vital sign for Black Canyon. Other important biotic vital signs include the status of riparian-obligate bird communities; peregrine falcon populations; biological soil crust communities; and spring, seep, and hanging-garden communities. The status of sagebrush plant communities also is an important vital sign, particularly in relation to habitat needs of Gunnison sagegrouse. Population status of two rare, endemic plants (*Gilia penstemoides* and *Sullivantia hapemanii* var. *purpusii*) are vital signs, although these are relatively low-priority overall.

Landscape-level patterns. Four vital signs associated with landscape-level attributes are high-priority monitoring needs for Black Canyon. These include land cover, land use, degree of park insularization, and landscape fragmentation and connectivity. The status of land-condition patterns also is an important vital sign for the park. Over 60 percent of the park's boundary is shared with private land owners (Table 20, Evenden et al. 2002), emphasizing the potential for surrounding landscape patterns to affect ecological conditions within the park.

Stressors. Black Canyon has identified four stressor-oriented vital signs as high-priority monitoring needs. These include park visitor-use patterns, invasive exotic plants, changes in hydrologic regimes due to upstream reservoir operation, and adjacent / upstream land-use activities.

Other natural resource values. The status of natural night skies and soundscapes also are vital signs for Black Canyon, but these are of relatively low priority.

Bryce Canyon National Park

Bryce Canyon National Park has identified 18 vital signs that are high-priority monitoring needs (Table 8). Nine of these currently are monitored, although existing monitoring will be reevaluated in relation to vital-signs needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Bryce Canyon because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network. Wind patterns, which also affect multiple ecological processes (e.g., energy balance, evaporative demand, fire behavior, spatial redistribution of soil resources), currently are monitored via RAWS fire-weather stations.

Air quality. Bryce Canyon is classified as a Class I area under the Clean Air Act. As a consequence, all vital signs related to air quality are high-priority monitoring needs. All currently are monitored in the park.

Table 8. Vital signs for Bryce Canyon National Park (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Bryce Canyon and across the NCPN as a whole. Vital signs that are currently monitored are indicated by “Yes” or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority		Currently Monitored?
			BRCA	NCPN	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
		Air temperature patterns	XXX	XXX	Yes
		Wind patterns	XX	XX	Yes
Air quality		Atmospheric deposition	XXX	XXX	BRCA (wet dep.)
		Visibility	XXX	XXX	BRCA
		Tropospheric ozone levels	XXX	XXX	BRCA (passive)
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XXX	XXX	
		Stream flow regime	X	XXX	
		Stream / wetland hydrologic function	X	XXX	
		Groundwater dynamics	XX	XXX	
Water quality		SEE WATER QUALITY TABLE 25	XXX	XXX	
Disturbance regimes		Fire regimes	XXX	XXX	Yes
		Hillslope erosion processes	XX	X	
		Extreme climatic events	XX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	XX	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XX	XXX	Yes
	At-risk species or communities	Status of at-risk species – amphibian populations		XX	
		Status of at-risk species – bat populations	X	XX	
		Status of at-risk species – Mexican spotted owl populations		XXX	
		Status of at-risk species – peregrine falcon populations	X		Yes
		Status of at-risk species – Utah prairie dog populations	XXX		Yes
		Status of at-risk species – TES plant populations (spp. vary by park)		XXX	
		Status of at-risk communities – riparian-obligate birds		XXX	
		Status of at-risk communities – sagebrush-obligate birds		XX	
		Status of at-risk communities – pinyon-juniper-obligate birds		XX	
		Status of at-risk communities – native fish communities		XX	
		Status of at-risk communities – native grassland / meadow plant communities	XX	XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities		XXX	
		Status of at-risk / focal communities – riparian / wetland plant communities	XX	XXX	
	Focal species or communities	Status of focal communities – biological soil crusts		XXX	
		Status of focal communities – aquatic macroinvertebrates	X	XXX	
		Status of focal / unique communities – spring, seep, & hanging-garden communities	XXX	XXX	
	Endemic species or unique communities	Status of rare / endemic plant populations – mulitple species	XX	XXX	Yes
		Status of other unique communities (communities vary by park)		X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XX	XX	
		Park insularization	XX	XXX	
		Landscape fragmentation and connectivity	XX	XXX	

Table 8 continued.

Category	VITAL SIGN	Priority		Currently Monitored?
		BRCA	NCPN	
Other vital-sign categories				
Stressors	Park use by visitors	XXX	XXX	Yes
	Invasive exotic plants	XXX	XXX	Yes
	Invasive, exotic, and/or feral animals	X	XX	
	Occurrence patterns of novel diseases / pathogens	X	X	
	Permitted consumptive / extractive activities on park lands	X	X	
	Park administration and operations	XX	XX	
	Changes in stream hydrologic regimes due to surface-water diversions	X	XX	
	Changes in stream hydrologic regimes due to large reservoirs		XX	
	Changes in groundwater hydrologic regimes due to groundwater extraction	XX	XX	
	Adjacent / upstream land-use activities	XX	XXX	
	Non-compliant uses on park lands	X	XX	
Other natural resource values	Status of paleontological resources	XXX	X	
	Status of natural night skies	XXX	XX	
	Status of natural soundscapes	XX	XX	Yes

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Bryce Canyon because of their significance for the sustainability of upland ecosystems and because of their sensitivity to visitor-use impacts and natural disturbances such as fire. None of these currently are monitored at Bryce Canyon. Because of the abundance of springs and seeps at Bryce Canyon, groundwater dynamics is an important vital sign for the park. Stream flow and hydrologic function also have been identified as vital signs, but these are relatively low-priority needs since few lotic systems are found at Bryce Canyon and these are ephemeral or intermittent in nature.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Bryce Canyon. See the water-quality discussion (below) for details.

Disturbance regimes. Wildfire is the predominant natural disturbance in forests and meadows above the rim at Bryce Canyon. As a consequence, the status of fire regimes is a high-priority vital sign for the park. Along the retreating rim of the Pink Cliffs and below the rim in the breaks of the Claron Formation, hillslope erosion is the primary natural disturbance. Very little is known about the ecological role of hillslope erosion in landscapes such as the Claron breaks, but substrate instability probably has important implications for population dynamics of vascular plants (including edaphic endemics) and other ecological processes. Because of its widespread significance in the park, the status of hillslope erosional processes has been identified as an important vital sign for Bryce Canyon. This vital sign is closely related to upland soil / site stability (described above). Soil and hillslope erosional processes both may be accelerated by human activities. Extreme climatic events (which interact with erosional processes) and insect / disease outbreaks in forests and woodlands also are important vital signs for the park.

Biotic integrity. Two high-priority biotic vital signs have been identified by Bryce Canyon. These are the status of Utah prairie dog populations (federally listed threatened species) and the status of focal spring, seep, and hanging-garden communities. Other important biotic vital signs include the status of predominant upland plant communities (primarily in relation to fire regimes), native grassland / meadow plant communities (regionally at-risk), and riparian / wetland plant communities (regionally at-risk). Numerous rare, endemic plant species are found at Bryce Canyon. The population status of these species also is an important vital sign for the park.

Landscape-level patterns. Land cover and land use both are high-priority vital signs for Bryce Canyon. The status of land-condition patterns, degree of park insularization, and landscape fragmentation and connectivity also are important vital signs for the park, but they have not been identified as high-priority monitoring needs.

Stressors. Two vital-signs associated with pro-active monitoring of anthropogenic stressors have been identified by Bryce Canyon as high-priority monitoring needs. These are park visitor-use patterns and invasive exotic plants. Both of these currently are monitored, although the adequacy of existing monitoring will be reevaluated during the Phase III process. Other important (but lesser priority) stressor-oriented vital signs include park administration and operations, changes in hydrologic regimes due to groundwater extraction, and adjacent / upstream land-use activities.

Other natural resource values. Bryce Canyon National Park is well known for the undiminished quality of its natural night skies. Less well known but equally impressive is the quality of paleontological resources found in the park. The park has identified the status of both of these resources as high-priority vital signs.

Canyonlands National Park

Canyonlands National Park has identified 33 high-priority vital signs (Table 9). Nineteen of these currently are monitored to one degree or another, although existing monitoring will be reevaluated in relation to vital-signs needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Canyonlands because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network and several automated stations. Wind patterns – also an important vital sign – currently are monitored via automated stations associated with air-quality monitoring and long-term ecological research (see monitoring summaries in Phase I report).

Air quality. Canyonlands is classified as a Class I area under the Clean Air Act. As a consequence, all vital signs related to air quality are high-priority monitoring needs. All currently are monitored in the park.

Soil, water, and nutrient dynamics. Vital signs associated with upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority monitoring needs for Canyonlands because of their significance for the sustainability of upland ecosystems and because of their sensitivity to visitor-use impacts. Two important lotic ecosystems (the Colorado River and Salt Creek) are found in the park. As a consequence, stream flow regime and hydrologic function also are high-priority vital signs. Groundwater-dependent springs, seeps, and hanging gardens are focal ecosystems that are relatively abundant in Canyonlands. Thus groundwater dynamics is another high-priority vital sign for the park.

Table 9. Vital signs for Canyonlands National Park (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Canyonlands and across the NCPN as a whole. Vital signs that are currently monitored are indicated by “Yes” or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority CANY	Priority NCPN	Currently Monitored?
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
		Air temperature patterns	XXX	XXX	Yes
		Wind patterns	XX	XX	Yes
Air quality		Atmospheric deposition	XXX	XXX	CANY
		Visibility	XXX	XXX	CANY
		Tropospheric ozone levels	XXX	XXX	CANY
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XXX	XXX	
		Stream flow regime	XXX	XXX	Yes
		Stream / wetland hydrologic function	XXX	XXX	Yes
		Groundwater dynamics	XXX	XXX	
Water quality		SEE WATER QUALITY TABLE 26	XXX	XXX	Yes
Disturbance regimes		Fire regimes	X	XXX	
		Extreme climatic events	XXX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	X	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XXX	XXX	Yes
	At-risk species or communities	Status of at-risk species – amphibian populations	XX	XX	
		Status of at-risk species – bat populations	XX	XX	
		Status of at-risk species – Mexican spotted owl populations	XXX	XXX	Yes
		Status of at-risk species – peregrine falcon populations	XX		
		Status of at-risk species – endangered fish populations	XXX		Yes
		Status of at-risk species – TES plant populations (spp. vary by park)		XXX	
		Status of at-risk communities – riparian-obligate birds	XXX	XXX	Yes
		Status of at-risk communities – sagebrush-obligate birds		XX	
		Status of at-risk communities – pinyon-juniper-obligate birds	XX	XX	
		Status of at-risk communities – native fish communities	XXX	XX	
		Status of at-risk communities – native grassland / meadow plant communities	XXX	XXX	Yes
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities		XXX	
		Status of at-risk / focal communities – riparian / wetland plant communities	XXX	XXX	Yes
	Focal species or communities	Status of focal communities – biological soil crusts	XXX	XXX	Yes
		Status of focal communities – aquatic macroinvertebrates	XXX	XXX	Yes
		Status of focal / unique communities – spring, seep, & hanging-garden communities	XXX	XXX	
	Endemic species or unique communities	Status of rare / endemic plant populations – multiple species	X	XXX	
		Status of unique communities – relict plant communities	XX	X	
		Status of unique communities – tinaja / waterpocket communities	XX	X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XX	XX	
		Park insularization	XX	XXX	
		Landscape fragmentation and connectivity	XX	XXX	

Table 9 continued.

Category	VITAL SIGN	Priority		Currently Monitored?
		CANY	NCPN	
Other vital-sign categories				
Stressors	Park use by visitors	XXX	XXX	Yes
	Invasive exotic plants	XXX	XXX	
	Invasive, exotic, and/or feral animals	XXX	XX	
	Occurrence patterns of novel diseases / pathogens	X	X	
	Permitted consumptive / extractive activities on park lands		X	
	Park administration and operations	XXX	XX	
	Changes in stream hydrologic regimes due to surface-water diversions	X	XX	
	Changes in stream hydrologic regimes due to large reservoirs	XX	XX	
	Changes in groundwater hydrologic regimes due to groundwater extraction		XX	
	Adjacent / upstream land-use activities	XXX	XXX	
	Non-compliant uses on park lands	XXX	XX	
Other natural resource values	Status of paleontological resources	XX	X	
	Status of natural night skies	XXX	XX	Yes
	Status of natural soundscapes	XXX	XX	

Water quality. Water quality is a high-priority component of vital-signs monitoring at Canyonlands. See the water-quality discussion (below) for details.

Disturbance regimes. Other than stream-flow events (which are captured under flow regime, above), extreme climatic events are the predominant natural disturbances at Canyonlands. Because of this, monitoring of such events has been identified as a high priority for the park.

Biotic integrity. Continued monitoring of predominant upland plant communities, riparian / wetland plant communities, and grassland plant communities is a high priority for Canyonlands. The current emphasis of vegetation monitoring at Canyonlands is to assess dynamics of plant communities in relation to climatic fluctuations and natural disturbances (see summary of existing monitoring in Phase I report). Riparian-obligate bird communities currently are monitored at Canyonlands, and continued monitoring is a high priority in coordination with regional-level bird-monitoring efforts (see discussion in network-level overview). Four federally endangered fish species are found in the Colorado River, and the population status of these species is a high-priority monitoring need for the park. These species currently are monitored in conjunction with the Colorado River Recovery Program. Expanding beyond the four listed species, the status of native fish communities is a high-priority vital sign for the park. As indicated in the network overview, Canyonlands also supports a breeding population of Mexican spotted owls (federally threatened species). Owl population status is a high-priority vital sign for Canyonlands. The status of biological soil crust communities and aquatic macroinvertebrate communities (focal communities) are high-priority vital signs for Canyonlands because of their functional significance for upland and aquatic ecosystems, respectively. Springs, seeps, and hanging gardens – focal ecosystems emphasized in the network program – are relatively abundant at Canyonlands. The condition of these ecosystems is a high-priority vital sign that is not currently monitored in the park. Canyonlands supports several upland communities / ecosystems that are considered to be land-use relicts or climatic relicts. The condition of these systems is an important vital sign for the park because of their unique nature and restricted extent. Likewise, the status of unique tinaja communities / ecosystems, pinyon-juniper-obligate bird communities, native fish communities, peregrine falcon populations, bat populations, and amphibian populations also are important vital signs for the park.

Landscape-level patterns. Land cover and land use patterns, particularly adjacent to the park, have been identified as high-priority vital signs for Canyonlands. Land-condition patterns, degree of park insularization, and landscape fragmentation and connectivity (again, emphasizing adjacent lands) also are important vital signs for the park.

Stressors. Six vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Canyonlands as high-priority monitoring needs. These are park visitor-use patterns, invasive exotic plants, invasive exotic animals (emphasizing exotic fish in the Colorado River system), park administration / operations (e.g., road and trail maintenance activities), adjacent / upstream land-use activities, and non-compliant uses on park lands (e.g., trespass livestock grazing). Other important stressor-oriented vital signs concern changes in hydrologic regimes due to large reservoirs.

Other natural resource values. The status of paleontological resources, natural night skies and soundscapes also are important vital signs for Canyonlands. Baseline data pertaining to night-sky darkness currently are being collected in the park.

Capitol Reef National Park

Capitol Reef National Park has identified 37 high-priority vital signs (Table 10). Of these, 20 currently are monitored to one degree or another. In all cases, the adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Capitol Reef because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network. Wind patterns – also an important vital sign for Capitol Reef due to effects on multiple ecological processes – are monitored via an automated station located near park headquarters.

Air quality. Capitol Reef is classified as a Class I area under the Clean Air Act. As a consequence, all vital signs related to air quality are high priority. Atmospheric ozone (passive, during summer) and airborne particulate levels (visibility measure) are the only air-quality vital signs currently monitored at Capitol Reef.

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Capitol Reef because of their significance for the sustainability of upland ecosystems and because of their sensitivity to impacts from visitor-use activities and domestic livestock. The Fremont River and four perennial streams are found in the park. As a consequence, stream flow regime and hydrologic function also are high-priority vital signs. Groundwater-dependent springs, seeps, and hanging gardens are focal ecosystems also found in Capitol Reef. Thus groundwater dynamics is another high-priority vital sign for the park.

Table 10. Vital signs for Capitol Reef National Park (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Capitol Reef and across the NCPN as a whole. Vital signs that are currently monitored are indicated by “Yes” or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority		Currently Monitored?
			CARE	NCPN	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
		Air temperature patterns	XXX	XXX	Yes
		Wind patterns	XX	XX	Yes
Air quality		Atmospheric deposition	XXX	XXX	CANY (115 km E)
		Visibility	XXX	XXX	CARE
		Tropospheric ozone levels	XXX	XXX	CARE (passive)
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XXX	XXX	
		Stream flow regime	XXX	XXX	
		Stream / wetland hydrologic function	XXX	XXX	
		Groundwater dynamics	XXX	XXX	
Water quality		SEE WATER QUALITY TABLE 27	XXX	XXX	
Disturbance regimes		Fire regimes	X	XXX	
		Extreme climatic events	XXX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	X	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XXX	XXX	
	At-risk species or communities	Status of at-risk species – amphibian populations	X	XX	
		Status of at-risk species – bat populations	X	XX	
		Status of at-risk species – Mexican spotted owl populations	XXX	XXX	Yes
		Status of at-risk species – peregrine falcon populations	X		Yes
		Status of at-risk species – other TES vertebrate populations (spp. vary by park)			
		Status of at-risk species – *Pediocactus despaini*	XXX	XXX	Yes
		Status of at-risk species – *Pediocactus winkleri*	XXX	XXX	Yes
		Status of at-risk species – *Townsendia aprica*	XXX	XXX	Yes
		Status of at-risk species – *Schoenocrambe barnebyi*	XXX	XXX	Yes
		Status of at-risk species – *Spiranthes diluvialis*	XXX	XXX	Yes
		Status of at-risk species – *Gilia caespitosa*	XXX	XXX	Yes
		Status of at-risk species – *Sclerocactus wrightiae*	XXX	XXX	Yes
		Status of at-risk species – *Astragalus harrisonii*	XXX	XXX	Yes
		Status of at-risk species – *Gilia tenuis*	XXX	XXX	Yes
		Status of at-risk communities – riparian-obligate birds	XXX	XXX	Yes
		Status of at-risk communities – sagebrush-obligate birds	XX	XX	
		Status of at-risk communities – pinyon-juniper-obligate birds	X	XX	
		Status of at-risk communities – native fish communities	XX	XX	
		Status of at-risk communities – native grassland / meadow plant communities	XXX	XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities		XXX	
		Status of at-risk / focal communities – riparian / wetland plant communities	XXX	XXX	
	Focal species or communities	Status of focal communities – biological soil crusts	XX	XXX	
		Status of focal communities – aquatic macroinvertebrates	XX	XXX	

Table 10 continued.

Category		VITAL SIGN	Priority CARE	Priority NCPN	Currently Monitored?
Ecosystem characteristics					
Biotic integrity	Focal species or communities	Status of focal / unique communities – spring, seep, & hanging-garden communities	XXX	XXX	
	Endemic species or unique communities	Status of rare / endemic plant populations – (see at-risk species, above)	XXX	XXX	Yes
		Status of unique communities –pinyon-juniper / pygmy sage communities	X	X	
		Status of unique communities – pinyon -juniper / cushion plant communities	X	X	
		Status of unique communities – hop hornbeam / boxelder communities	X	X	
		Status of unique communities – bristlecone / cushion plant communities	X	X	
		Status of unique communities – tinaja / waterpocket communities	XX	X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XXX	XX	
		Park insularization	XX	XXX	
		Landscape fragmentation and connectivity	XX	XXX	
Other vital-sign categories					
Stressors		Park use by visitors	XXX	XXX	Yes
		Invasive exotic plants	XXX	XXX	
		Invasive, exotic, and/or feral animals	X	XX	
		Occurrence patterns of novel diseases / pathogens	X	X	
		Permitted consumptive / extractive activities on park lands	XXX	X	Yes
		Park administration and operations	X	XX	
		Changes in stream hydrologic regimes due to surface-water diversions	XX	XX	
		Changes in stream hydrologic regimes due to large reservoirs		XX	
		Changes in groundwater hydrologic regimes due to groundwater extraction	X	XX	
		Adjacent / upstream land-use activities	XXX	XXX	
		Non-compliant uses on park lands	XXX	XX	
Other natural resource values		Status of paleontological resources	X	X	
		Status of natural night skies	XX	XX	
		Status of natural soundscapes	XX	XX	

Water quality. Water quality is a high-priority component of vital-signs monitoring at Capitol Reef. See the water-quality discussion (below) for details.

Disturbance regimes. Other than stream-flow events (which are captured under flow regime, above), extreme climatic events are the predominant natural disturbances at Capitol Reef. Because of this, monitoring of such events has been identified as a high priority for the park.

Biotic integrity. The status of predominant upland plant communities is a high-priority vital sign for Capitol Reef. Upland vegetation monitoring at Capitol Reef is expected to be oriented towards the assessment of dynamics in relation to past and on-going land-use activities (e.g., livestock grazing), natural disturbances, and climatic fluctuations. Vital signs associated with riparian plant communities (focal systems); spring, seep, and hanging-garden communities (focal systems); and grassland plant communities (at-risk systems) also are high-priority monitoring needs for Capitol Reef. Nine plant species in the park are federally listed or are candidates for listing (Table 10; Phase I report). Monitoring the status of these species is a high priority for the park. As indicated in the network overview, numerous other endemic plant taxa are found in

Capitol Reef and the status of endemic plant populations has been identified as a high-priority vital sign for the network as a whole. The status of Mexican spotted owl populations (federally threatened species) is a high-priority monitoring need for the park. Riparian-obligate bird communities currently are monitored at Capitol Reef, and continued monitoring is a high priority in coordination with regional-level bird-monitoring efforts (see discussion in network-level overview). Biological soil crusts and aquatic macroinvertebrate communities are important vital signs for the park because of their functional significance for upland and aquatic ecosystems, respectively. Native fish communities (regionally at-risk) and communities associated with unique tinaja or waterpocket ecosystems also are important vital signs for Capitol Reef. The status of sagebrush-obligate bird communities is an important vital sign for Capitol Reef, although the pertinent shrubsteppe community found in Capitol Reef is better characterized as high desert scrub (dominated by *Sarcobatus vermiculatus*, with a minor *Artemisia* component) than as sagebrush steppe. Both vegegation types are important for "sagebrush obligates" and associated species (Parrish et al. 2002:209). Finally, four vascular plant communities have been identified as vital signs at Capitol Reef because of their unique character and restricted extent (Romme et al. 1993). These are pinyon-juniper / pygmy sagebrush (*Artemisia pygmaea*) communities; pinyon-juniper / cushion plant communities (ground layer dominated by one or more cushion-plant species such as *Phlox muscoides*, *Erigeron compositus*, many others); hophornbeam (*Ostrya knowltonii*) / boxelder (*Acer negundo*) riparian woodland communities; and bristlecone (*Pinus longaeva*) / cushion plant communities. None of these have been identified as high priorities relative to other monitoring needs.

Landscape-level patterns. Land cover and land use have been identified as high-priority vital signs by Capitol Reef. The status of land-condition patterns also is a high-priority monitoring need due to permitted livestock operations and restoration needs associated with past land-use activities. Degree of park insularization, as well as landscape fragmentation and connectivity also are important vital signs for the park.

Stressors. Five vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Capitol Reef as high-priority monitoring needs because of their potential impacts on park resources. These include visitor-use patterns, invasive exotic plants, permitted consumptive / extractive activities on park lands (livestock grazing and associated activities), adjacent / upstream land-use activities, and non-compliant uses.

Other natural resource values. The status of natural night skies and soundscapes also are important vital signs for Capitol Reef. The status of paleonotological resources is a vital sign for the park, but it a low priority relative to other needs.

Cedar Breaks National Monument

Cedar Breaks National Monument has identified 13 high-priority vital signs (Table 11). Of these, only three currently are monitored to one degree or another. In all cases, the adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Cedar Breaks because of their significance as drivers of ecosystem variability and change.

Both currently are monitored nearby at Blowhard Mountain in conjunction with the National Weather Service Cooperative Network. Wind patterns, which also affect multiple ecological processes (e.g., energy balance, evaporative demand, fire behavior), are not currently monitored at or near Cedar Breaks.

Air quality. Cedar Breaks is a Class II area under the Clean Air Act. Cedar Breaks has identified air-quality attributes as important (but not high-priority) vital signs. As discussed in the network overview, modeling indicates the potential for a "hot spot" of N deposition in the vicinity of Cedar Breaks due to upwind emissions from Las Vegas, Nevada, and St. George, Utah (Fenn et al. 2003a). The adequacy for Cedar Breaks of current wet and dry deposition monitoring at Bryce Canyon and the Grand Canyon, respectively, will be assessed during the Phase III process.

Table 11. Vital signs for Cedar Breaks National Monument (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Cedar Breaks and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority		Currently Monitored?
			CEBR	NCPN	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes (Blowhard Mtn.)
		Air temperature patterns	XXX	XXX	Yes (Blowhard Mtn.)
		Wind patterns	XX	XX	
Air quality		Atmospheric deposition	XX	XXX	BRCA (wet dep., 65 km E), GRCA (dry dep., 180 km S)
		Visibility	XX	XXX	BRCA, ZION
		Tropospheric ozone levels	XX	XXX	ZION
Soil, water, and nutrient dynamics		Upland soil / site stability	XX	XXX	
		Upland hydrologic function	XX	XXX	
		Nutrient cycling	XX	XXX	
		Stream flow regime		XXX	
		Stream / wetland hydrologic function	X	XXX	
		Groundwater dynamics		XXX	
Water quality		SEE WATER QUALITY TABLE 28	X	XXX	
Disturbance regimes		Fire regimes	XXX	XXX	
		Hillslope erosional processes	XXX	X	
		Extreme climatic events	XX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	XXX	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XXX	XXX	
	At-risk species or communities	Status of at-risk species – amphibian populations		XX	
		Status of at-risk species – bat populations	XX	XX	
		Status of at-risk species – Mexican spotted owl populations		XXX	
		Status of at-risk species – peregrine falcon populations	X		
		Status of at-risk species – other TES vertebrate populations (spp. vary by park)			
		Status of at-risk species – *Salix arizonica* populations	XXX	XXX	
		Status of at-risk communities – riparian-obligate birds		XXX	
		Status of at-risk communities – sagebrush-obligate birds		XX	
		Status of at-risk communities – pinyon-juniper-obligate birds		XX	

Table 11 continued.

Category		VITAL SIGN	Priority		Currently Monitored?
			CEBR	NCPN	
Ecosystem characteristics					
Biotic integrity	At-risk species or communities	Status of at-risk communities – native fish communities		XX	
		Status of at-risk communities – native grassland / meadow plant communities	XXX	XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities		XXX	
	Focal species or communities	Status of at-risk / focal communities – riparian / wetland plant communities	XX	XXX	
		Status of focal communities – biological soil crusts		XXX	
		Status of focal communities – aquatic macroinvertebrates		XXX	
	Endemic species or unique communities	Status of focal / unique communities – spring, seep, & hanging-garden communities	X	XXX	
		Status of rare / endemic plant populations – multiple species	XX	XXX	
		Status of unique communities – bristlecone pine communities	XX	X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XX	XX	
		Park insularization	XXX	XXX	
		Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories					
Stressors		Park use by visitors	XXX	XXX	Yes
		Invasive exotic plants	XXX	XXX	
		Invasive, exotic, and/or feral animals	X	XX	
		Occurrence patterns of novel diseases / pathogens	X	X	
		Permitted consumptive / extractive activities on park lands		X	
		Park administration and operations	X	XX	
		Changes in stream hydrologic regimes due to surface-water diversions		XX	
		Changes in stream hydrologic regimes due to large reservoirs		XX	
		Changes in groundwater hydrologic regimes due to groundwater extraction		XX	
		Adjacent / upstream land-use activities	XX	XXX	
		Non-compliant uses on park lands	X	XX	
Other natural resource values		Status of paleontological resources		X	
		Status of natural night skies	X	XX	
		Status of natural soundscapes	XX	XX	

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are important vital signs for Cedar Breaks because of their significance for the sustainability of upland ecosystems and because of their sensitivity to visitor-use impacts. Wetland hydrologic function also is a vital sign for Cedar Breaks. Threats to these ecosystem attributes currently are relatively low, therefore none of these vital signs are high-priority monitoring needs for Cedar Breaks.

Water quality. Water-quality vital signs have been identified for Cedar Breaks, but these are not high-priority monitoring needs for the park. See the water-quality discussion (below) for details.

Disturbance regimes. Wildfire and insect / disease outbreaks are the predominant natural disturbances in forests above the rim at Cedar Breaks. Consequently, these are high-priority vital signs for the park. Along the retreating rim of the Pink Cliffs and below the rim in the breaks of the Claron Formation, hillslope erosion is the primary natural disturbance. Very little is known about the ecological role of hillslope erosion in landscapes such as the Claron breaks, but substrate instability probably has important implications for population dynamics of vascular plants (including edaphic endemics) and other ecological processes. Because of its widespread significance in the park, the status of hillslope erosional processes has been identified as an important vital sign for Cedar Breaks. This vital sign is closely related to upland soil / site stability (described above). Soil and hillslope erosional processes both may be accelerated by human activities. Extreme climatic events (which affect erosional processes, fire occurrence, and insect / disease outbreaks) also is an important vital sign for the park.

Biotic integrity. The status of predominant upland plant communities and native grassland / meadow plant communities are high-priority vital signs for Cedar Breaks. Above the breaks, the park is an ungrazed island bordered to the east by lands managed for multiple uses – including grazing by domestic sheep. Monitoring data documenting dynamics of ungrazed grassland / meadow vegetation in relation to climatic fluctuations can potentially provide important reference information pertinent to the management of adjacent lands. In addition, integrated vegetation monitoring at Cedar Breaks and Zion National Park (see below) has the potential to provide information concerning climate-vegetation relationships over a 2000-m elevational gradient. The existence of this steep elevational gradient over a 50-km horizontal distance may provide important opportunities for leveraging financial resources to investigate questions pertaining to global change.

In addition to these biotic vital signs, the status of Arizona willow (*Salix arizonica*; currently managed under a conservation agreement) populations is a high-priority monitoring need for the park. The status of bat populations, wetland plant communities, unique bristlecone-pine communities, and endemic plant populations also are important vital signs for the park, although these currently are not high-priority needs.

Landscape-level patterns. Four vital signs associated with landscape-level attributes are high-priority monitoring needs for Cedar Breaks. These are land cover, land use, degree of park insularization, and landscape fragmentation and connectivity. The status of land-condition patterns also is an important vital sign for the park. The plateau portion of the park is a narrow strip of land borded to the east by significant private holdings mixed with multiple-use lands managed by the U.S.D.A. Forest Service (see Appendix A, Evenden et al. 2002).

Stressors. Two vital-signs associated with pro-active monitoring of anthropogenic stressors have been identified by Cedar Breaks as high-priority monitoring needs. These are park visitor-use patterns and invasive exotic plants. The status of adjacent land-use activities (e.g., development, logging and grazing) also is an important vital sign. Visitor-use levels currently are monitored, but the adequacy of existing monitoring will be reevaluated during the Phase III process.

Other natural resource values. The status of of natural night skies and soundscapes are vital signs for Cedar Breaks, but neither of these currently is a high-priority monitoring need.

Colorado National Monument

Colorado National Monument (NM) has identified 18 high-priority vital signs (Table 12). Of these, only four currently are monitored to one degree or another. The adequacy of this existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Colorado NM because of their significance as drivers of ecosystem variability and change. Both currently are monitored in the park in conjunction with the National Weather Service Cooperative Network. Wind patterns, which also affect multiple ecological processes (e.g., energy balance, evaporative demand, fire behavior), are not currently monitored

Air quality. Colorado NM is a Class II area under the Clean Air Act. The park has identified air-quality attributes as important (but not high-priority) vital signs.

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Colorado NM because of their significance for the sustainability of upland ecosystems and because of their sensitivity to impacts from visitor-use activities and natural disturbances such as fire. Although the park only supports ephemeral and intermittent streams, stream flow regime is a high-priority vital sign (see water-quality discussion below). Hydrologic function also is an important vital signs, although this is of lesser priority.

Water quality. Water quality is an important component of vital-signs monitoring at Colorado NM. See the water-quality discussion (below) for details.

Table 12. Vital signs for Colorado National Monument (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Colorado National Monument and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority		Currently Monitored?
			COLM	NCPN	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
		Air temperature patterns	XXX	XXX	Yes
		Wind patterns	XX	XX	
Air quality		Atmospheric deposition	XX	XXX	Sunlight Pk. (wet dep., 110 km NE), CANY (dry dep., 130 km SW)
		Visibility	XX	XXX	CANY (130 km SW)
		Tropospheric ozone levels	XX	XXX	CANY (130 km SW)
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XXX	XXX	
		Stream flow regime	XXX	XXX	
		Stream / wetland hydrologic function	XX	XXX	
		Groundwater dynamics	X	XXX	
Water quality		SEE WATER QUALITY TABLE 29	XX	XXX	
Disturbance regimes		Fire regimes	XXX	XXX	
		Extreme climatic events	XXX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	XX	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XX	XXX	

Table 12 continued.

<table>
<tr><th colspan="2" rowspan="2">Category</th><th rowspan="2">VITAL SIGN</th><th colspan="2">Priority</th><th rowspan="2">Currently Monitored?</th></tr>
<tr><th>COLM</th><th>NCPN</th></tr>
<tr><td colspan="6">Ecosystem characteristics</td></tr>
<tr><td rowspan="20">Biotic integrity</td><td rowspan="13">At-risk species or communities</td><td>Status of at-risk species – amphibian populations</td><td>X</td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk species – bat populations</td><td>X</td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk species – Mexican spotted owl populations</td><td></td><td rowspan="3">XXX</td><td></td></tr>
<tr><td>Status of at-risk species – peregrine falcon populations</td><td>X</td><td>Yes</td></tr>
<tr><td>Status of at-risk species – other TES vertebrate populations (spp. vary by park)</td><td></td><td></td></tr>
<tr><td>Status of at-risk species – TES plant populations (spp. vary by park)</td><td></td><td>XXX</td><td></td></tr>
<tr><td>Status of at-risk communities – riparian-obligate birds</td><td></td><td>XXX</td><td></td></tr>
<tr><td>Status of at-risk communities – sagebrush-obligate birds</td><td></td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk communities – pinyon-juniper-obligate birds</td><td>XX</td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk communities – native fish communities</td><td></td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk communities – native grassland / meadow plant communities</td><td></td><td>XXX</td><td></td></tr>
<tr><td>Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities</td><td>X</td><td>XXX</td><td></td></tr>
<tr><td>Status of at-risk / focal communities – riparian / wetland plant communities</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td rowspan="3">Focal species or communities</td><td>Status of focal communities – biological soil crusts</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Status of focal communities – aquatic macroinvertebrates</td><td></td><td>XXX</td><td></td></tr>
<tr><td>Status of focal / unique communities – spring, seep, & hanging-garden communities</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td rowspan="2">Endemic species or unique communities</td><td>Status of rare / endemic plant populations – Lomatium latilobum populations</td><td>X</td><td>XXX</td><td></td></tr>
<tr><td>Status of other unique communities –Arctostaphylos patula communities</td><td>X</td><td>X</td><td></td></tr>
<tr><td colspan="2" rowspan="5">Landscape-level patterns</td><td>Land cover</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Land use</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Land condition</td><td>XX</td><td>XX</td><td></td></tr>
<tr><td>Park insularization</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Landscape fragmentation and connectivity</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td colspan="6">Other vital-sign categories</td></tr>
<tr><td colspan="2" rowspan="11">Stressors</td><td>Park use by visitors</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Invasive exotic plants</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Invasive, exotic, and/or feral animals</td><td>XX</td><td>XX</td><td></td></tr>
<tr><td>Occurrence patterns of novel diseases / pathogens</td><td>X</td><td>X</td><td></td></tr>
<tr><td>Permitted consumptive / extractive activities on park lands</td><td></td><td>X</td><td></td></tr>
<tr><td>Park administration and operations</td><td>X</td><td>XX</td><td></td></tr>
<tr><td>Changes in stream hydrologic regimes due to surface-water diversions</td><td></td><td>XX</td><td></td></tr>
<tr><td>Changes in stream hydrologic regimes due to large reservoirs</td><td></td><td>XX</td><td></td></tr>
<tr><td>Changes in groundwater hydrologic regimes due to groundwater extraction</td><td>X</td><td>XX</td><td></td></tr>
<tr><td>Adjacent / upstream land-use activities</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Non-compliant uses on park lands</td><td>X</td><td>XX</td><td></td></tr>
<tr><td colspan="2" rowspan="3">Other natural resource values</td><td>Status of paleontological resources</td><td></td><td>X</td><td></td></tr>
<tr><td>Status of natural night skies</td><td>XX</td><td>XX</td><td></td></tr>
<tr><td>Status of natural soundscapes</td><td>XX</td><td>XX</td><td></td></tr>
</table>

Disturbance regimes. Wildfire and extreme climatic events are the predominant natural disturbances at Colorado NM. These are high-priority vital signs because of their significance as drivers of ecosystem variability and change. The occurrence of insect / disease outbreaks (which can be strongly related to climate) also is an important vital sign for the park.

Biotic integrity. Because of their functional significance, the status of three focal community types are high-priority biotic vital signs for the park – riparian / wetland plant communities, biological soil crust communities, and spring, seep, and hanging-garden communities. Vital signs associated with the status of predominant upland plant communities and pinyon-juniper obligate bird communities also are important for the park. The status of *Lomatium latilobum* populations (a rare endemic plant) and relict communities dominated by *Arctostaphylos patula* also are vital signs, although these are low priority relative to other monitoring needs.

Landscape-level patterns. Urban-interface issues are a major concern for Colorado NM (almost 50 percent of the Monument boundary is shared with private land owners – see Table 20 and Appendix A, Evenden et al. 2002). Consequently, four vital signs associated with broad-scale landscape-level attributes are high-priority monitoring needs for the park. These include land cover, land use, degree of park insularization, and landscape fragmentation and connectivity. The status of land-condition patterns also is an important vital sign for the park.

Stressors. Three vital signs associated with pro-active monitoring of anthropogenic stressors potentially impacting park resources are high-priority monitoring needs for the park. These include visitor-use patterns, invasive exotic plants, and adjacent land-use activities. Of these, only visitor-use patterns currently are monitored. Existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process. Due to urban encroachment, the status of exotic, invasive, and/or feral animals also is an important vital sign for the park.

Other natural resource values. The status of natural night skies and soundscapes also are important vital signs for the park.

Curecanti National Recreation Area

Curecanti National Recreation Area (NRA) has identified 21 high-priority vital signs (Table 13). Of these, eight currently are monitored to one degree or another. The adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Curecanti because of their significance as drivers of ecosystem variability and change. These currently are monitored at Curecanti in conjunction with the National Weather Service Cooperative Network. Wind patterns, which also affect multiple ecological processes, are not currently monitored at Curecanti.

Air quality. Curecanti is classified as a Class II area under the Clean Air Act. Air-quality attributes are important (but not high-priority) vital signs for Curecanti.

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Curecanti because of their significance for the sustainability of upland ecosystems and because of their sensitivity to impacts from visitor-use activities and domestic livestock. Because of the abundance and ecological significance of perennial streams in Curecanti, stream flow regime and stream hydrologic function are high-priority vital signs for the NRA.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Curecanti. See the water-quality discussion (below) for details.

Table 13. Vital signs for Curecanti National Recreation Area (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Colorado National Monument and across the NCPN as a whole. Vital signs that are currently monitored are indicated by “Yes” or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority		Currently Monitored?
			CURE	NCPN	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
		Air temperature patterns	XXX	XXX	Yes
		Wind patterns	XX	XX	
Air quality		Atmospheric deposition	XX	XXX	Gothic, CO (70 km NE)
		Visibility	XX	XXX	Weminuche Wilderness Area (100 km S)
		Tropospheric ozone levels	XX	XXX	BLCA (passive)
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XXX	XXX	
		Stream flow regime	XXX	XXX	Yes
		Stream / wetland hydrologic function	XXX	XXX	
		Groundwater dynamics	X	XXX	
Water quality		SEE WATER QUALITY TABLE 30	XXX	XXX	Yes
Disturbance regimes		Fire regimes	XX	XXX	
		Extreme climatic events	XXX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	X	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XXX	XXX	
	At-risk species or communities	Status of at-risk species – amphibian populations	X	XX	
		Status of at-risk species – bat populations		XX	
		Status of at-risk species – Mexican spotted owl populations		XXX	
		Status of at-risk species – peregrine falcon populations	X		Yes
		Status of at-risk species – Gunnison sagegrouse populations	XXX		Yes
		Status of at-risk species – TES plant populations (spp. vary by park)		XXX	
		Status of at-risk communities – riparian-obligate birds	XX	XXX	Yes
		Status of at-risk communities – sagebrush-obligate birds	XX	XX	
		Status of at-risk communities – pinyon-juniper-obligate birds		XX	
		Status of at-risk communities – native fish communities		XX	
		Status of at-risk communities – native grassland / meadow plant communities		XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities	XXX	XXX	
		Status of at-risk / focal communities – riparian / wetland plant communities	XX	XXX	
	Focal species or communities	Status of focal communities – biological soil crusts	XX	XXX	
		Status of focal communities – aquatic macroinvertebrates	XXX	XXX	Yes
		Status of focal communities – aquatic macrophyte communities	XX		
		Status of focal communities – reservoir zooplankton communities	XX		
		Status of focal communities – reservoir phytoplankton communities	XX		
	Endemic species or unique communities	Status of focal / unique communities – spring, seep, & hanging-garden communities	X	XXX	

Table 13 continued.

Category		VITAL SIGN	Priority		Currently Monitored?
			CURE	NCPN	
Ecosystem characteristics					
Biotic integrity	Endemic species or unique communities	Status of rare / endemic plant populations – *Gilia penstemoides*, *Sullivantia hapemanii* var. *purpusii*, *Astragalus microcymbus*, *A. anisus*	X	XXX	
		Status of other unique communities (communities vary by park)		X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XX	XX	
		Park insularization	XXX	XXX	
		Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories					
Stressors		Park use by visitors	XXX	XXX	Yes
		Invasive exotic plants	XXX	XXX	
		Invasive, exotic, and/or feral animals	X	XX	
		Occurrence patterns of novel diseases / pathogens	X	X	
		Permitted consumptive / extractive activities on park lands	XX	X	
		Park administration and operations	XX	XX	
		Changes in stream hydrologic regimes due to surface-water diversions	XX	XX	
		Changes in stream hydrologic regimes due to large reservoirs	XXX	XX	
		Changes in groundwater hydrologic regimes due to groundwater extraction		XX	
		Adjacent / upstream land-use activities	XXX	XXX	
		Non-compliant uses on park lands	X	XX	
Other natural resource values		Status of paleontological resources	X	X	
		Status of natural night skies		XX	
		Status of natural soundscapes		XX	

Disturbance regimes. Other than stream-flow events (which are captured under flow regime, above), extreme climatic events are the predominant natural disturbances at Curecanti. As a consequence, monitoring of extreme events has been identified as a high priority for the NRA. Because of the significance of wildfire in the NRA, the status of fire regimes also is an important vital sign.

Biotic integrity. The status of predominant upland plant communities is a high-priority vital sign for Curecanti. Upland vegetation monitoring at Curecanti is expected to be oriented towards the assessment of dynamics in relation to past and on-going land-use activities (e.g., livestock grazing), natural disturbances, and climatic fluctuations. In the case of Curecanti, the predominant upland plant community type is sagebrush shrubland / shrubsteppe – an at-risk ecosystem identified for emphasis by the network. The status of sagebrush plant communities is a high-priority vital sign for the NRA, particularly in relation to habitat needs of Gunnison sagegrouse (candidate for federal listing). The status of sagegrouse populations also is a high-priority vital sign. Biological soil crust communities, riparian-wetland plant communities, riparian-obligate birds, and sagebrush-obligate birds also are important vital signs for the NRA.

Given the significance of aquatic resources in Curecanti, the status of aquatic macroinvertebrate communities has been identified as a high-priority vital sign for the NRA. Because of their functional importance, aquatic macrophyte communities, reservoir zooplankton communities, and reservoir phytoplankton communities all have been identified as vital signs for Curecanti – although none of these is a high-priority monitoring need.

Finally, Curecanti supports populations of three rare, endemic plant species. The status of these populations is a vital sign for the NRA, although this is a low priority relative to other monitoring needs.

Landscape-level patterns. Four vital signs associated with landscape-level attributes are high-priority monitoring needs for Curecanti. These include land cover, land use, degree of park insularization, and landscape fragmentation and connectivity. The status of broad-scale land-condition patterns also is an important vital sign for the NRA due to the spatial extent of permitted livestock grazing. Over 50 percent of the park's boundary is shared with private land owners (Table 20, Evenden et al. 2002), and due to its narrow shape the NRA has a relatively high perimeter:area ratio (14.8:1) for its size. Both of these facts indicate the great potential for surrounding landscape patterns to affect ecological conditions within the park.

Stressors. Four vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Curecanti as high-priority monitoring needs because of their potential impacts on park resources. These include visitor-use patterns, invasive exotic plants, changes in hydrologic regimes due to reservoir operations, and adjacent / upstream land-use activities. Permitted consumptive / extractive activities on park lands (i.e., livestock grazing and associated activities), park administration and operations, and changes in hydrologic regimes due to surface-water diversions also have been identified as important vital signs for the NRA.

Other natural resource values. The status of paleontological resources also is a vital sign for Curecanti, although this is a low priority relative to ecological vital signs.

Dinosaur National Monument

Dinosaur National Monument has identified 33 high-priority vital signs (Table 14). Of these, 14 currently are monitored to one degree or another. The adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Table 14. Vital signs for Dinosaur National Monument (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Dinosaur and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category	VITAL SIGN	Priority		Currently Monitored?
		DINO	NCPN	
Ecosystem characteristics				
Climatic conditions	Precipitation patterns	XXX	XXX	Yes
	Air temperature patterns	XXX	XXX	Yes
	Wind patterns	XX	XX	Yes
Air quality	Atmospheric deposition	XX	XXX	Sand Spring (wet dep., 80 km E), CANY (dry dep., 240 km SW)
	Visibility	XX	XXX	Mt. Zirkel Wilderness (150 km E)
	Tropospheric ozone levels	XX	XXX	CANY (240 km SW)

Table 14 continued.

Category		VITAL SIGN	Priority		Currently Monitored?
			DINO	NCPN	
Ecosystem characteristics					
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XXX	XXX	
		Stream flow regime	XXX	XXX	Yes
		Stream / wetland hydrologic function	XXX	XXX	Yes
		Groundwater dynamics	X	XXX	
Water quality		SEE WATER QUALITY TABLE 31	XXX	XXX	
Disturbance regimes		Fire regimes	XXX	XXX	Yes
		Extreme climatic events	XXX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	X	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XXX	XXX	Yes
	At-risk species or communities	Status of at-risk species – amphibian populations	X	XX	
		Status of at-risk species – bat populations	X	XX	
		Status of at-risk species – Mexican spotted owl populations	X		
		Status of at-risk species – peregrine falcon populations	XXX	XXX	Yes
		Status of at-risk species – endangered fish populations	XXX		Yes
		Status of at-risk species – *Spiranthes diluvialis* populations	XX	XXX	Yes
		Status of at-risk communities – riparian-obligate birds	XXX	XXX	
		Status of at-risk communities – sagebrush-obligate birds	X	XX	
		Status of at-risk communities – pinyon-juniper-obligate birds	X	XX	
		Status of at-risk communities – native fish communities	XXX	XX	Yes
		Status of at-risk communities – native grassland / meadow plant communities	XXX	XXX	Yes
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities	XXX	XXX	Yes
		Status of at-risk / focal communities – riparian / wetland plant communities	XXX	XXX	Yes
	Focal species or communities	Status of focal communities – biological soil crusts	XXX	XXX	
		Status of focal communities – aquatic macroinvertebrates	XX	XXX	
		Status of focal / unique communities – spring, seep, & hanging-garden communities	XX	XXX	
	Endemic species or unique communities	Status of rare / endemic plant populations – multiple species	XXX	XXX	
		Status of other unique communities (communities vary by park)		X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XXX	XX	
		Park insularization	XXX	XXX	
		Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories					
Stressors		Park use by visitors	XXX	XXX	Yes
		Invasive exotic plants	XXX	XXX	
		Invasive, exotic, and/or feral animals	XXX	XX	
		Occurrence patterns of novel diseases / pathogens	X	X	
		Permitted consumptive / extractive activities on park lands	XXX	X	
		Park administration and operations	X	XX	
		Changes in stream hydrologic regimes due to surface-water diversions	XX	XX	
		Changes in stream hydrologic regimes due to large reservoirs	XXX	XX	
		Changes in groundwater hydrologic regimes due to groundwater extraction	X	XX	
		Adjacent / upstream land-use activities	XXX	XXX	
		Non-compliant uses on park lands	XX	XX	
Other natural resource values		Status of paleontological resources	XXX	X	
		Status of natural night skies	XX	XX	
		Status of natural soundscapes	XXX	XX	

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Dinosaur because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network. Wind patterns – also an important vital sign for Dinosaur due to effects on multiple ecological processes – are monitored via an automated RAWS fire-weather station.

Air quality. Dinosaur is classified as a Class II area under the Clean Air Act. Air-quality attributes have been identified as important vital signs for Dinosaur. Given the distance of existing monitoring stations (Table 14), Maniero (2001) noted that particulate monitoring (as a form of visibility monitoring) and continuous ozone monitoring should be considered for Dinosaur.

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Dinosaur because of their significance for the sustainability of upland ecosystems and because of their sensitivity to impacts from visitor-use activities, domestic livestock and wildfire. The Green and Yampa rivers are central to the ecological integrity of Dinosaur. Because of their significance for the sustainability of riparian and aquatic ecosystems associated with these rivers, stream flow regime and stream hydrologic function have been identified as high-priority vital signs for Dinosaur.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Dinosaur. See the water-quality discussion (below) for details.

Disturbance regimes. Other than stream-flow events (which are captured under flow regime, above), wildfire and extreme climatic events are the predominant natural disturbances at Dinosaur. As a consequence, these have been identified as high-priority vital signs for the park.

Biotic integrity. The status of predominant upland plant communities is a high-priority vital sign for Dinosaur. Upland vegetation monitoring at Dinosaur is expected to be oriented towards the assessment of dynamics in relation to past and on-going land-use activities (e.g., livestock grazing), prescribed and natural wildfire, and climatic fluctuations. Monitoring of this vital sign will be integrated with four other high-priority biotic vital signs – the status of riparian / wetland plant communities, native grassland / meadow plant communities, sagebrush shrubland / shrubsteppe plant communities, and biological soil crust communities. Other high-priority biotic vital signs include the status of peregrine falcon populations (see network-level discussion, above) and riparian-obligate bird communities. As in the Colorado River through Canyonlands, four federally endangered fish species are found in the Green and Yampa Rivers in Dinosaur, and the population status of these species is a high-priority monitoring need for the park. These species currently are monitored in conjunction with the Colorado River Recovery Program. The status of native fish communities (in general) also is a high-priority vital sign. As indicated in the network overview, Dinosaur supports a large number of endemic plant taxa, and the status of endemic plant populations has been identified as a high-priority vital sign for the network as a whole. The status of *Spiranthes diluvialis* populations (federally listed threatened species); aquatic macroinvertebrates (focal community); and spring, seep, and hanging-garden communities (focal communities) also are important vital signs for Dinosaur NM.

Landscape-level patterns. Land cover and land use patterns have been identified as high-priority vital signs by Dinosaur. The status of land-condition patterns also is a high-priority monitoring need for Dinosaur due to permitted livestock operations in the park. Degree of park insularization, as well as landscape fragmentation and connectivity also are high-priority vital signs due to the development potential of private in-holdings within the park and extensive private lands in the area surrounding the park. Almost 20 percent of Dinosaur's boundary is shared with private land owners (Table 20, Evenden et al. 2002).

Stressors. Six vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Dinosaur as high-priority monitoring needs because of their potential impacts on park resources. These include visitor-use patterns; invasive exotic plants; invasive, exotic, and/or feral animals (particularly non-native fish in the Green and Yampa rivers); permitted consumptive / extractive activities on park lands (livestock grazing and associated activities); adjacent / upstream land-use activities; and changes in stream hydrologic regimes due to reservoir operations.

Other natural resource values. The status of paleontological resources and natural soundscapes also have been identified by Dinosaur as high-priority vital signs. The status of natural night skies is another important vital sign for the park.

Fossil Butte National Monument

Fossil Butte National Monument has identified 21 high-priority vital signs (Table 15). Of these, six currently are monitored to one degree or another. The adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Fossil Butte because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network. Wind patterns – which also affect multiple ecological processes – are not currently monitored in the Monument.

Air quality. Fossil Butte is classified as a Class II area under the Clean Air Act. Air-quality attributes have been identified as important (but not high-priority) vital signs for the park. However, because of the proximity of industrial activity to Fossil Butte (an open-pit coal mine and a coal-fired power generation station are within 12 miles of the park), it will be important during the Phase III process to assess the adequacy of distant monitoring stations for tracking air quality conditions at Fossil Butte. As discussed in the network-level overview, modeling also indicates the potential for a "hot spot" of N deposition in the vicinity of Fossil Butte due to upwind emissions from Salt Lake City and the Wasatch Front (Fenn et al. 2003a).

Table 15. Vital signs for Fossil Butte National Monument (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Fossil Butte and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority: FOBU	Priority: NCPN	Currently Monitored?
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
		Air temperature patterns	XXX	XXX	Yes
		Wind patterns	XX	XX	
Air quality		Atmospheric deposition	XX	XXX	Murphy Ridge, UT (wet dep., 60 km SW); Pinedale, WY (dry dep., 130 km NE)
		Visibility	XX	XXX	Bridger Wildern. Area (150 km NE)
		Tropospheric ozone levels	XX	XXX	Logan, UT (90 km W)
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XXX	XXX	
		Stream flow regime	X	XXX	
		Stream / wetland hydrologic function	XXX	XXX	Yes
		Groundwater dynamics	XXX	XXX	Yes
Water quality		SEE WATER QUALITY TABLE 32	XX	XXX	
Disturbance regimes		Fire regimes	XXX	XXX	
		Extreme climatic events	XXX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	XX	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XXX	XXX	
	At-risk species or communities	Status of at-risk species – amphibian populations		XX	
		Status of at-risk species – bat populations	X	XX	
		Status of at-risk species – Mexican spotted owl populations		XXX	
		Status of at-risk species – peregrine falcon populations			
		Status of at-risk species – pygmy rabbit populations	XXX		
		Status of at-risk species – greater sagegrouse populations	XXX		
		Status of at-risk species – TES plant populations (spp. vary by park)		XXX	
		Status of at-risk communities – riparian-obligate birds		XXX	
		Status of at-risk communities – sagebrush-obligate birds	XX	XX	
		Status of at-risk communities – pinyon-juniper-obligate birds		XX	
		Status of at-risk communities – native fish communities		XX	
		Status of at-risk communities – native grassland / meadow plant communities		XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities	XXX	XXX	
		Status of at-risk / focal communities – riparian / wetland plant communities	XX	XXX	
	Focal species or communities	Status of focal communities – biological soil crusts	XX	XXX	
		Status of focal communities – aquatic macroinvertebrates	XX	XXX	
		Status of focal / unique communities – spring, seep, & hanging-garden communities	XX	XXX	
	Endemic species or unique communities	Status of rare / endemic plant populations – *Lepidium integrifolium* var. *integrifolium* populations; *Physaria condensata* populations	X	XXX	
		Status of other unique communities (communities vary by park)		X	

Table 15 continued.

Category	VITAL SIGN	Priority		Currently Monitored?
		FOBU	NCPN	
Ecosystem characteristics				
Landscape-level patterns	Land cover	XXX	XXX	
	Land use	XXX	XXX	
	Land condition	XX	XX	
	Park insularization	XXX	XXX	
	Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories				
Stressors	Park use by visitors	XXX	XXX	Yes
	Invasive exotic plants	XXX	XXX	
	Invasive, exotic, and/or feral animals	X	XX	
	Occurrence patterns of novel diseases / pathogens	X	X	
	Permitted consumptive / extractive activities on park lands	XX	X	
	Park administration and operations	XX	XX	
	Changes in stream hydrologic regimes due to surface-water diversions	XXX	XX	
	Changes in stream hydrologic regimes due to large reservoirs		XX	
	Changes in groundwater hydrologic regimes due to groundwater extraction		XX	
	Adjacent / upstream land-use activities	XX	XXX	
	Non-compliant uses on park lands	X	X	
Other natural resource values	Status of paleontological resources	XXX	X	
	Status of natural night skies	X	XX	
	Status of natural soundscapes	X	XX	

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Fossil Butte because of their significance for the sustainability of upland ecosystems and because of their sensitivity to impacts from visitor-use activities, domestic livestock and wildfire. Past land-use activities (primarily livestock grazing) in Fossil Butte significantly affected the hydrologic functioning of uplands and ephemeral / intermittent stream channels in the park. Because of this and on-going restoration activities, stream hydrologic functioning is a high-priority vital sign for Fossil Butte. Numerous springs and other groundwater-dependent systems occur in Fossil Butte. Thus groundwater-dynamics is another high-priority vital sign for the park.

Water quality. Water quality is an important component of vital-signs monitoring for Fossil Butte. See the water-quality discussion (below) for details.

Disturbance regimes. Wildfire and extreme climatic events are the predominant natural disturbances at Fossil Butte. As a consequence, these have been identified as high-priority vital signs for the park.

Biotic integrity. The status of predominant upland plant communities is a high-priority vital sign for Fossil Butte. Upland vegetation monitoring at Fossil Butte is expected to be oriented towards the assessment of dynamics in relation to past and on-going land-use activities (e.g., livestock grazing and trailing), restoration activities, herbivory by native ungulate populations (elk, moose, mule deer), prescribed and natural wildfire, and climatic fluctuations.

In the case of Fossil Butte, the predominant upland plant community type is sagebrush shrubland / shrubsteppe – an at-risk ecosystem identified for emphasis by the network. The status of sagebrush plant communities is a high-priority vital sign for Fossil Butte, particularly in relation to habitat needs of pygmy rabbit populations (*Brachylagus idahoensis*) and greater sagegrouse populations (*Centrocercus urophasianus*). The U.S. Fish and Wildlife service currently is considering a petition to list pygmy rabbit populations throughout the Great Basin and Intermountain West as threatened under the ESA (the Columbia Basin population currently is listed as endangered), and sagegrouse populations have declined throughout most of the species' range in western North America during the past few decades (Connelly and Braun 1997). Habitat degradation and fragmentation have been cited as major factors contributing to declines in these sagebrush-dependent species (e.g., Connelly et al. 2000). The population status of these two species is a high-priority monitoring need for Fossil Butte.

Other important biotic vital signs for Fossil Butte include the status of sagebrush-obligate bird communities (i.e., in addition to sagegrouse), riparian-wetland plant communities, biological soil crust communities, aquatic macroinvertebrate communities, and spring / seep communities. Finally, Fossil Butte supports populations of two rare, endemic plant species. The status of these populations is a vital sign for the park, although this is a low priority relative to other monitoring needs.

Landscape-level patterns. Four vital signs associated with landscape-level attributes are high-priority monitoring needs for Fossil Butte. These include land cover, land use, degree of park insularization, and landscape fragmentation and connectivity. The status of land-condition patterns also is an important vital sign for the park. Significant amounts of private lands are located in the area surrounding Fossil Butte, and due to its size the park has a relatively high perimeter:area ratio (9.8:1). Surrounding landscape patterns have great potential for affecting ecological conditions within the park.

Stressors. Three vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Fossil Butte as high-priority monitoring needs because of their potential impacts on park resources. These include visitor-use patterns, invasive exotic plants, and changes in stream hydrologic regimes due to surface-water diversions. Permitted extractive activities (i.e., permitted stock trailing), park administration / operations and adjacent / upstream land-use activities (including predator-control actions) also are important stressor-oriented vital signs for Fossil Butte.

Other natural resource values. The status of paleontological resources found at Fossil Butte is another high-priority vital sign for the park. The status of natural night skies and soundscapes also are vital signs, but these are low priority relative to other monitoring needs.

Golden Spike National Historic Site

Golden Spike National Historic Site has identified 15 high-priority vital signs (Table 16). Of these, only two are currently monitored. Adequacy of existing monitoring will be reevaluated during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Golden Spike because of their significance as drivers of ecosystem variability and change. The status of wind patterns in the park is another important vital sign, particularly because of its significance for fire behaviour. Golden Spike is the only unit within the NCPN where there is no existing monitoring of climatic conditions.

Table 16. Vital signs for Golden Spike National Historic Site (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Golden Spike and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority		Currently Monitored?
			GOSP	NCPN	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	
		Air temperature patterns	XXX	XXX	
		Wind patterns	XX	XX	
Air quality		Atmospheric deposition	XX	XXX	Logan, UT (wet dep., 65 km NE); Pinedale, WY (dry dep., 240 km E)
		Visibility	XX	XXX	Craters of the Moon NM, ID (160 km NW)
		Tropospheric ozone levels	XX	XXX	Brigham City, UT (50 km E)
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XXX	XXX	
		Stream flow regime		XXX	
		Stream / wetland hydrologic function		XXX	
		Groundwater dynamics		XXX	
Water quality		SEE WATER QUALITY SECTION		XXX	
Disturbance regimes		Fire regimes	XXX	XXX	Yes
		Extreme climatic events	XXX	XXX	
		Insect / disease outbreaks in forests and woodlands		XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XX	XXX	
	At-risk species or communities	Status of at-risk species – amphibian populations		XX	
		Status of at-risk species – bat populations		XX	
		Status of at-risk species – Mexican spotted owl populations		XXX	
		Status of at-risk species – peregrine falcon populations			
		Status of at-risk species – other TES vertebrate populations (spp. vary by park)			
		Status of at-risk species – TES plant populations (spp. vary by park)		XXX	
		Status of at-risk communities – riparian-obligate birds		XXX	
		Status of at-risk communities – sagebrush-obligate birds	X	XX	
		Status of at-risk communities – pinyon-juniper-obligate birds		XX	
		Status of at-risk communities – native fish communities		XX	
		Status of at-risk communities – native grassland / meadow plant communities		XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities	XXX	XXX	
		Status of at-risk / focal communities – riparian / wetland plant communities		XXX	
	Focal species or communities	Status of focal communities – biological soil crusts		XXX	
		Status of focal communities – aquatic macroinvertebrates		XXX	
		Status of focal / unique communities – spring, seep, & hanging-garden communities		XXX	
	Endemic species or unique communities	Status of rare / endemic plant populations – (spp. vary by park)		XXX	

Table 16 continued.

Category		VITAL SIGN	Priority		Currently Monitored?
			GOSP	NCPN	
Ecosystem characteristics					
Biotic integrity	Endemic species or unique communities	Status of other unique communities (communities vary by park)		X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XX	XX	
		Park insularization	XXX	XXX	
		Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories					
Stressors		Park use by visitors	XXX	XXX	Yes
		Invasive exotic plants	XXX	XXX	
		Invasive, exotic, and/or feral animals	X	XX	
		Occurrence patterns of novel diseases / pathogens	X	X	
		Permitted consumptive / extractive activities on park lands		X	
		Park administration and operations	X	XX	
		Changes in stream hydrologic regimes due to surface-water diversions		XX	
		Changes in stream hydrologic regimes due to large reservoirs		XX	
		Changes in groundwater hydrologic regimes due to groundwater extraction	X	XX	
		Adjacent / upstream land-use activities	XXX	XXX	
		Non-compliant uses on park lands		XX	
Other natural resource values		Status of paleontological resources		X	
		Status of natural night skies	X	XX	
		Status of natural soundscapes	X	XX	

Air quality. Golden Spike is classified as a Class II area under the Clean Air Act. Air-quality attributes are important (but not high-priority) vital signs for the park. As discussed in the network overview, modeling indicates the potential for a "hot spot" of N deposition in the vicinity of Golden Spike due to emissions from Salt Lake City and the Wasatch Front (Fenn et al. 2003a). The adequacy the nearest monitoring stations for representing air-quality conditions at Golden Spike will be assessed during the Phase III process.

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Golden Spike because of their significance for the sustainability of upland ecosystems and because of their sensitivity to impacts from wildfire, adjacent land-use practices, and the legacy of past land-use practicies within the park.

Water quality. No water-quality vital signs have been identified for Golden Spike. See the water-quality discussion (below) for details.

Disturbance regimes. Wildfire and extreme climatic events are the predominant natural disturbances at Golden Spike. As a consequence, these have been identified as high-priority vital signs for the park.

Biotic integrity. The status of sagebrush shrubland / shrubsteppe plant communities (at-risk community type) has been identified as a high-priority vital sign for Golden Spike, particularly in relation to fire regimes and weed-removal efforts. The status of other upland plant communities also is an important (but not high-priority) vital sign for the park. The status of sagebrush-obligate bird communities also is a vital sign, but it is low priority relative to other monitoring needs.

Landscape-level patterns. Land cover, land use, degree of park insularization, and landscape fragmentation and connectivity all are high-priority landscape-level vital signs for the park. The status of land-condition patterns also is an important vital sign for Golden Spike. Golden Spike is the only unit in the NCPN that is completely surrounded by private lands, and because of its small size and linear shape it is characterized by a very high perimeter:area ratio (50:1, compared to 2:1 at Canyonlands). Of NCPN units, only Hovenweep and Pipe Spring have higher perimeter:area ratios (Table 20, Evenden et al. 2002). Ecological conditions within the park are strongly influenced by surrounding landscape patterns.

Stressors. Three vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Golden Spike as high-priority monitoring needs because of their potential impacts on park resources. These include visitor-use patterns, invasive exotic plants, and adjacent land-use activities. Relative to other parks in the network, current visitation levels probably do not significantly impact park ecosystems. However, this could change with increasing urbanization and land-use change.

Other natural resource values. The status of natural night skies and soundscapes are vital signs for the park, but these currently are low priority relative to other monitoring needs.

Hovenweep National Monument

Hovenweep National Monument has identified 23 high-priority vital signs (Table 17). Of these, 10 currently are monitored to one degree or another. The adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Hovenweep because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network. Wind patterns – which also affect multiple ecological processes – are not currently monitored in the park.

Air quality. Hovenweep is classified as a Class II area under the Clean Air Act. Air-quality attributes have been identified as important (but not high-priority) vital signs for the park.

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Hovenweep because of their significance for the sustainability of upland ecosystems and because of their sensitivity to impacts from visitor-use activities and natural disturbances such as wildfire. Because of the occurrence of focal, groundwater-dependent spring and seep ecosystems at Hovenweep, groundwater dynamics is another high-priority vital sign.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Hovenweep. See the water-quality discussion (below) for details.

Disturbance regimes. Extreme climatic events are the predominant natural disturbances at Hovenweep. As a consequence, monitoring of such events is a high priority for the park. The status of fire regimes also is an important vital sign for Hovenweep.

Table 17. Vital signs for Hovenweep National Monument (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Hovenweep and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority		Currently Monitored?
			HOVE	NCPN	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
		Air temperature patterns	XXX	XXX	Yes
		Wind patterns	XX	XX	
Air quality		Atmospheric deposition	XX	XXX	Mesa Verde NP
		Visibility	XX	XXX	CANY, Mesa Verde NP
		Tropospheric ozone levels	XX	XXX	Mesa Verde, NP
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XX	XXX	
		Stream flow regime		XXX	
		Stream / wetland hydrologic function		XXX	
		Groundwater dynamics	XXX	XXX	
Water quality		SEE WATER QUALITY TABLE 33	XXX	XXX	Yes
Disturbance regimes		Fire regimes	XX	XXX	
		Extreme climatic events	XXX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	X	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XXX	XXX	Yes
	At-risk species or communities	Status of at-risk species – amphibian populations		XX	
		Status of at-risk species – bat populations	XX	XX	
		Status of at-risk species – Mexican spotted owl populations		XXX	
		Status of at-risk species – peregrine falcon populations			
		Status of at-risk species – other TES vertebrate populations (spp. vary by park)			
		Status of at-risk species – TES plant populations (spp. vary by park)		XXX	
		Status of at-risk communities – riparian-obligate birds		XXX	
		Status of at-risk communities – sagebrush-obligate birds	XX	XX	
		Status of at-risk communities – pinyon-juniper-obligate birds		XX	
		Status of at-risk communities – native fish communities		XX	
		Status of at-risk communities – native grassland / meadow plant communities		XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities	XXX	XXX	Yes
		Status of at-risk / focal communities – riparian / wetland plant communities		XXX	
	Focal species or communities	Status of focal communities – biological soil crusts	XXX	XXX	Yes
		Status of focal communities – aquatic macroinvertebrates	XXX	XXX	Yes
		Status of focal / unique communities – spring, seep, & hanging-garden communities	XXX	XXX	
	Endemic species or unique communities	Status of rare / endemic plant populations – (spp. vary by park)		XXX	

Table 17 continued.

Category		VITAL SIGN	Priority		Currently Monitored?
			HOVE	NCPN	
Ecosystem characteristics					
Biotic integrity	Endemic species or unique communities	Status of other unique communities (communities vary by park)		X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XX	XX	
		Park insularization	XXX	XXX	
		Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories					
Stressors		Park use by visitors	XXX	XXX	Yes
		Invasive exotic plants	XXX	XXX	
		Invasive, exotic, and/or feral animals	XX	XX	
		Occurrence patterns of novel diseases / pathogens	X	X	
		Permitted consumptive / extractive activities on park lands		X	
		Park administration and operations	XXX	XX	
		Changes in stream hydrologic regimes due to surface-water diversions		XX	
		Changes in stream hydrologic regimes due to large reservoirs		XX	
		Changes in groundwater hydrologic regimes due to groundwater extraction	XXX	XX	
		Adjacent / upstream land-use activities	XX	XXX	
		Non-compliant uses on park lands	XX	XX	
Other natural resource values		Status of paleontological resources		X	
		Status of natural night skies	XXX	XX	Yes
		Status of natural soundscapes	XXX	XX	

Biotic integrity. Continued monitoring of predominant upland plant communities, which in this case includes sagebrush shrubland / shrubsteppe plant communities, is a high priority for Hovenweep. The current emphasis of vegetation monitoring at Hovenweep is to assess dynamics of plant communities in relation to climatic fluctuations and natural disturbances (see summary of existing monitoring in Phase I report). Monitoring the status of three focal community types also is a high priority for Hovenweep. These include biological soil crust communities; aquatic macroinvertebrate communities; and spring, seep, and hanging-garden communities. Additional important vital signs are the status of bat populations and the status of sagebrush-obligate bird communities.

Landscape-level patterns. Four vital signs associated with landscape-level attributes are high-priority monitoring needs for Hovenweep. These include land cover, land use, degree of park insularization, and landscape fragmentation and connectivity. The status of land-condition patterns also is an important vital sign for the park. Hovenweep is a small park comprised of six dispersed units surrounded by a variety of land ownerships (see Appendix A, Evenden et al. 2002). Almost 20 percent of the park boundary is shared with private land owners (Table 20, Evenden et al. 2002), and the park as a whole is characterized by a very high perimeter:area ratio (51:1, compared to 2:1 at Canyonlands). Individual units have even greater perimeter:area ratios. Ecological conditions within the park are strongly influenced by surrounding landscape patterns.

Stressors. Four vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Hovenweep as high-priority monitoring needs because of their potential impacts on park resources. These include visitor-use patterns, invasive exotic plants, park administration / operations, and changes in hydrologic regimes due to groundwater extraction.

The status of adjacent land-use activities and non-compliant uses on park lands also are important vital signs for the park.

Other natural resource values. The status of natural night skies and soundscapes both are high-priority vital signs for Hovenweep.

Natural Bridges National Monument

Natural Bridges National Monument has identified 24 high-priority vital signs (Table 18). Twelve of these currently are monitored to one degree or another. The adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Natural Bridges because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network. Wind patterns – which also affect multiple ecological processes – are not currently monitored in the park.

Table 18. Vital signs for Natural Bridges National Monument (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Natural Bridges and across the NCPN as a whole. Vital signs that are currently monitored are indicated by “Yes” or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

<table>
<tr><th colspan="2" rowspan="2">Category</th><th rowspan="2">VITAL SIGN</th><th colspan="2">Priority</th><th rowspan="2">Currently Monitored?</th></tr>
<tr><th>NABR</th><th>NCPN</th></tr>
<tr><td colspan="6">Ecosystem characteristics</td></tr>
<tr><td colspan="2" rowspan="3">Climatic conditions</td><td>Precipitation patterns</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Air temperature patterns</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Wind patterns</td><td>XX</td><td>XX</td><td></td></tr>
<tr><td colspan="2" rowspan="3">Air quality</td><td>Atmospheric deposition</td><td>XX</td><td>XXX</td><td>CANY</td></tr>
<tr><td>Visibility</td><td>XX</td><td>XXX</td><td>CANY</td></tr>
<tr><td>Tropospheric ozone levels</td><td>XX</td><td>XXX</td><td>CANY</td></tr>
<tr><td colspan="2" rowspan="6">Soil, water, and nutrient dynamics</td><td>Upland soil / site stability</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Upland hydrologic function</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Nutrient cycling</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Stream flow regime</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td>Stream / wetland hydrologic function</td><td>X</td><td>XXX</td><td></td></tr>
<tr><td>Groundwater dynamics</td><td>XXX</td><td>XXX</td><td></td></tr>
<tr><td colspan="2">Water quality</td><td>SEE WATER QUALITY TABLE 34</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td colspan="2" rowspan="3">Disturbance regimes</td><td>Fire regimes</td><td>XX</td><td>XXX</td><td></td></tr>
<tr><td>Extreme climatic events</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Insect / disease outbreaks in forests and woodlands</td><td>X</td><td>XX</td><td></td></tr>
<tr><td rowspan="9">Biotic integrity</td><td>Predominant plant communities</td><td>Status of predominant upland plant communities</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td rowspan="8">At-risk species or communities</td><td>Status of at-risk species – amphibian populations</td><td>X</td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk species – bat populations</td><td>XX</td><td>XX</td><td></td></tr>
<tr><td>Status of at-risk species – Mexican spotted owl populations</td><td></td><td rowspan="3">XXX</td><td></td></tr>
<tr><td>Status of at-risk species – peregrine falcon populations</td><td>X</td><td>Yes</td></tr>
<tr><td>Status of at-risk species – other TES vertebrate populations (spp. vary by park)</td><td></td><td></td></tr>
<tr><td>Status of at-risk species – TES plant populations (spp. vary by park)</td><td></td><td>XXX</td><td></td></tr>
<tr><td>Status of at-risk communities – riparian-obligate birds</td><td>XXX</td><td>XXX</td><td>Yes</td></tr>
<tr><td>Status of at-risk communities – sagebrush-obligate birds</td><td></td><td>XX</td><td></td></tr>
</table>

Table 18 continued.

Category		VITAL SIGN	Priority		Currently Monitored?
			NABR	NCPN	
Ecosystem characteristics					
Biotic integrity	At-risk species or communities	Status of at-risk communities – pinyon-juniper-obligate birds	XX	XX	
		Status of at-risk communities – native fish communities		XX	
		Status of at-risk communities – native grassland / meadow plant communities		XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities		XXX	
		Status of at-risk / focal communities – riparian / wetland plant communities	XXX	XXX	Yes
	Focal species or communities	Status of focal communities – biological soil crusts	XXX	XXX	Yes
		Status of focal communities – aquatic macroinvertebrates	XXX	XXX	Yes
		Status of focal / unique communities – spring, seep, & hanging-garden communities	XXX	XXX	
	Endemic species or unique communities	Status of rare / endemic plant populations – *Erigeron kachinensis* (Kachina daisy)	XXX	XXX	Yes
		Status of other unique communities (communities vary by park)		X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XX	XX	
		Park insularization	XX	XXX	
		Landscape fragmentation and connectivity	XX	XXX	
Other vital-sign categories					
Stressors		Park use by visitors	XXX	XXX	Yes
		Invasive exotic plants	XXX	XXX	
		Invasive, exotic, and/or feral animals	XX	XX	
		Occurrence patterns of novel diseases / pathogens	X	X	
		Permitted consumptive / extractive activities on park lands		X	
		Park administration and operations	XXX	XX	
		Changes in stream hydrologic regimes due to surface-water diversions	X	XX	
		Changes in stream hydrologic regimes due to large reservoirs		XX	
		Changes in groundwater hydrologic regimes due to groundwater extraction	XXX	XX	
		Adjacent / upstream land-use activities	XX	XXX	
		Non-compliant uses on park lands	XX	XX	
Other natural resource values		Status of paleontological resources		X	
		Status of natural night skies	XXX	XX	Yes
		Status of natural soundscapes	XXX	XX	

Air quality. Natural Bridges is classified as a Class II area under the Clean Air Act. Air-quality attributes have been identified as important (but not high-priority) vital signs for the park.

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Natural Bridges because of their significance for the sustainability of upland ecosystems and because of their sensitivity to impacts from visitor-use activities and natural disturbances such as wildfire. Because of the abundance of springs, hanging gardens, and perennial streams at Natural Bridges, stream flow regime and groundwater dynamics also are high-priority vital signs for the park.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Natural Bridges. See the water-quality discussion (below) for details.

Disturbance regimes. Extreme climatic events are the predominant natural disturbances at Natural Bridges. As a consequence, monitoring of such events is a high priority for the park. The status of fire regimes also is an important vital sign for Natural Bridges.

Biotic integrity. Continued monitoring of predominant upland plant communities and riparian / wetland plant communities is a high priority for Natural Bridges. The current emphasis of vegetation monitoring at Natural Bridges is to assess dynamics of plant communities in relation to climatic fluctuations and natural disturbances (see summary of existing monitoring in Phase I report). In addition to riparian / wetland plant communities, monitoring the status of three other focal community types also is a high priority for Natural Bridges. These include biological soil crust communities; aquatic macroinvertebrate communities; and spring, seep, and hanging-garden communities. Natural Bridges supports a population of a rare, endemic plant – *Erigeron kachinensis* (kachina daisy). The status of this population also is another high-priority vital sign for the park. The status of bat populations and pinyon-juniper-obligate bird communities are other important vital signs for Natural Bridges.

Landscape-level patterns. Land cover and land use both are high-priority landscape-level vital signs for the park. Land-condition patterns, degree of park insularization, and landscape fragmentation and connectivity also are important vital signs for Natural Bridges.

Stressors. Four vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Natural Bridges as high-priority monitoring needs because of their potential impacts on park resources. These are visitor-use patterns, invasive exotic plants, park administration / operations, and changes in hydrologic regimes due to groundwater extraction. The status of invasive, exotic, and feral animals; adjacent land-use activities; and non-compliant uses also are important vital signs for the park.

Other natural resource values. The status of natural night skies and soundscapes both are high-priority vital signs for Natural Bridges. Baseline data documenting current night-sky conditions are being collected by the park.

Pipe Spring National Monument

Pipe Spring National Monument has identified 13 high-priority vital signs (Table 19). Five of these currently are monitored to one degree or another. The adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Pipe Spring because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network. Wind patterns – which also affect multiple ecological processes – are not currently monitored in the park.

Air quality. Pipe Spring is classified as a Class II area under the Clean Air Act. Air-quality attributes have been identified as important (but not high-priority) vital signs for the park.

Table 19. Vital signs for Pipe Spring National Monument (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Pipe Spring and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		VITAL SIGN	Priority		Currently Monitored?
			PISP	NCPN	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
Climatic conditions		Air temperature patterns	XXX	XXX	Yes
Climatic conditions		Wind patterns	XX	XX	
Air quality		Atmospheric deposition	XX	XXX	BRCA (wet dep., 115 km NE); GRCA (120 km SE)
Air quality		Visibility	XX	XXX	ZION (45 km NW)
Air quality		Tropospheric ozone levels	XX	XXX	ZION (45 km NW)
Soil, water, and nutrient dynamics		Upland soil / site stability	XX	XXX	
Soil, water, and nutrient dynamics		Upland hydrologic function	XX	XXX	
Soil, water, and nutrient dynamics		Nutrient cycling	XX	XXX	
Soil, water, and nutrient dynamics		Stream flow regime		XXX	
Soil, water, and nutrient dynamics		Stream / wetland hydrologic function	X	XXX	
Soil, water, and nutrient dynamics		Groundwater dynamics	XXX	XXX	Yes
Water quality		SEE WATER QUALITY TABLE 35	XXX	XXX	
Disturbance regimes		Fire regimes		XXX	
Disturbance regimes		Extreme climatic events	XXX	XXX	Yes
Disturbance regimes		Insect / disease outbreaks in forests and woodlands	X	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	X	XXX	
Biotic integrity	At-risk species or communities	Status of at-risk species – amphibian populations	X	XX	
Biotic integrity	At-risk species or communities	Status of at-risk species – bat populations	XX	XX	
Biotic integrity	At-risk species or communities	Status of at-risk species – Mexican spotted owl populations		XXX	
Biotic integrity	At-risk species or communities	Status of at-risk species – peregrine falcon populations			
Biotic integrity	At-risk species or communities	Status of at-risk species – other TES vertebrate populations (spp. vary by park)			
Biotic integrity	At-risk species or communities	Status of at-risk species – TES plant populations (spp. vary by park)		XXX	
Biotic integrity	At-risk species or communities	Status of at-risk communities – riparian-obligate birds	XX	XXX	
Biotic integrity	At-risk species or communities	Status of at-risk communities – sagebrush-obligate birds	XX	XX	
Biotic integrity	At-risk species or communities	Status of at-risk communities – pinyon-juniper-obligate birds	XX	XX	
Biotic integrity	At-risk species or communities	Status of at-risk communities – native fish communities		XX	
Biotic integrity	At-risk species or communities	Status of at-risk communities – native grassland / shrubsteppe plant communities	X	XXX	
Biotic integrity	At-risk species or communities	Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities		XXX	
Biotic integrity	At-risk species or communities	Status of at-risk / focal communities – riparian / wetland plant communities	X	XXX	
Biotic integrity	Focal species or communities	Status of focal communities – biological soil crusts		XXX	
Biotic integrity	Focal species or communities	Status of focal communities – aquatic macroinvertebrates		XXX	
Biotic integrity	Focal species or communities	Status of focal / unique communities – spring, seep, & hanging-garden communities	X	XXX	
Biotic integrity	Endemic species or unique communities	Status of rare / endemic plant populations – (spp. vary by park)		XXX	
Biotic integrity	Endemic species or unique communities	Status of other unique communities (communities vary by park)		X	
Landscape-level patterns		Land cover	XXX	XXX	
Landscape-level patterns		Land use	XXX	XXX	
Landscape-level patterns		Land condition	XX	XX	

Table 19. continued.

Category	VITAL SIGN	Priority		Currently Monitored?
		PISP	NCPN	
Ecosystem characteristics				
Landscape-level patterns	Park insularization	XXX	XXX	
	Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories				
Stressors	Park use by visitors	XXX	XXX	Yes
	Invasive exotic plants	XXX	XXX	
	Invasive, exotic, and/or feral animals	X	XX	
	Occurrence patterns of novel diseases / pathogens	X	X	
	Permitted consumptive / extractive activities on park lands		X	
	Park administration and operations	X	XX	
	Changes in stream hydrologic regimes due to surface-water diversions		XX	
	Changes in stream hydrologic regimes due to large reservoirs		XX	
	Changes in groundwater hydrologic regimes due to groundwater extraction	XXX	XX	
	Adjacent / upstream land-use activities	XXX	XXX	
	Non-compliant uses on park lands		XX	
Other natural resource values	Status of paleontological resources		X	
	Status of natural night skies		XX	
	Status of natural soundscapes		XX	

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are important vital signs for Pipe Spring because of their significance for the sustainability of upland ecosystems and because of their sensitivity to impacts from visitor-use activities and natural disturbances such as wildfire. Because of the importance of springs to the mission of the park, groundwater dynamics is a high-priority monitoring need for Pipe Spring.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Pipe Spring. See the water-quality discussion (below) for details.

Disturbance regimes. Extreme climatic events are the predominant natural disturbances at Pipe Spring. As a consequence, monitoring of such events is a high priority for the park.

Biotic integrity. Four groups of at-risk populations or communities have been identified as important vital signs for Pipe Spring. The importance of these vital signs largely derives from the presence of spring-fed riparian / aquatic systems (albeit dominated by ornamental vegetation) and good-condition high desert scrub systems that are important "habitat islands" for wildlife on the Arizona Strip. The status of bat populations, riparian-obligate bird communities, and sagebrush-obligate bird communities all are important vital signs due to their association with these habitat islands. The status of sagebrush-obligate bird communities is identified as a vital sign for Pipe Spring even though the shrubsteppe community found in the Monument is better characterized as high desert scrub (dominated by *Atriplex canescens* and *Sarcobatus vermiculatus*, with a minor *Artemisia* component – M. Johnson, pers. comm.) than sagebrush steppe. Both vegegation types are important for "sagebrush obligates" and associated species (Parrish et al. 2002:209). Finally, the status of pinyon-juniper obligate bird communities also is an important vital sign for Pipe Spring. As in other NCPN units, it is anticipated that bird monitoring at Pipe Spring will be oriented towards participation in regional-scale monitoring efforts.

Landscape-level patterns. Because of its small size (16 ha), Pipe Spring is characterized by an extremely high perimeter:area ratio (99:1, compared to 2:1 at Canyonlands). In terms of land ownership and ecological condition, the park is truly an island. Land cover, land use, degree of park insularization, and landscape fragmentation and connectivity all are high-priority landscape-level vital signs for the park. The status of land-condition patterns also is an important vital sign for Pipe Spring.

Stressors. Four vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Pipe Spring as high-priority monitoring needs because of their potential impacts on park resources. These include visitor-use patterns, invasive exotic plants, changes in groundwater hydrologic regimes due to groundwater extraction, and other adjacent / upstream land-use activities.

Timpanogos Cave National Monument

Timpanogos Cave National Monument has identified 18 high-priority vital signs (Table 20). Ten of these currently are monitored to one degree or another. The adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process. Relative to other NCPN units, a unique feature of Timpanogos Cave is the need to monitor the status of ecological conditions both within and outside of the cave environment. Where pertinent, cave-specific vital signs have been differentiated from "external" vital signs in Table 20 and the associated discussion.

Climatic conditions. Because of their significance as drivers of ecosystem variability and change, temperature patterns and precipitation patterns are high-priority vital signs for Timpanogos Cave. External atmospheric pressure is an important factor affecting cave atmospheric circulation patterns. As a consequence, atmospheric pressure also has been identified as a high-priority vital sign. Within-cave air temperature and relative humidity patterns are high-priority vital signs because of their significance for geologic and biotic processes inside the cave. Wind patterns and cave atmospheric flow patterns also are important but are not high-priority monitoring needs.

Air quality. Timpanogos Cave is classified as a Class II area under the Clean Air Act. Air-quality attributes have been identified as important (but not high-priority) vital signs for the park. As discussed in the network-level overview, modeling indicates the potential for a "hot spot" of N deposition in the vicinity of Timpanogos due to upwind emissions from Salt Lake City and the Wasatch Front (Fenn et al. 2003a).

Soil, water, and nutrient dynamics. Cave soil quality and cave hydrologic regime both are high-priority vital signs for Timpanogos Cave. For purposes of assessment and monitoring, cave soil quality is defined as the capacity of cave soils or substrates to function as habitat for native cave biota. Cave hydrologic regime is a major driver of geological processes as well as biotic processes within the cave. Relative to these, vital signs related to external soil, water, and nutrient dynamics are low priority.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Timpanogos Cave, emphasizing waters within the cave. See the water-quality discussion (below) for details.

Table 20. Vital signs for Timpanogos Cave National Monument (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Timpanogos Cave and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		**VITAL SIGN**	**Priority**		**Currently Monitored?**
			TICA	**NCPN**	
Ecosystem characteristics					
Climatic conditions		External precipitation patterns	XXX	XXX	Yes
		External air temperature patterns	XXX	XXX	Yes
		External wind patterns	XX	XX	Yes
		External atmospheric pressure	XXX	X	Yes
		Cave air temperature patterns	XXX	X	Yes
		Cave relative humidity patterns	XXX	X	Yes
		Cave air-flow patterns	XX	X	
Air quality		Atmospheric deposition	XX	XXX	Murphy Ridge, UT (wet dep., 115 km NE); GRBA (dry dep., 270 km SW)
		Visibility	XX	XXX	CARE (230 km S)
		Tropospheric ozone levels	XX	XXX	Provo, UT
Soil, water, and nutrient dynamics		Upland soil / site stability	X	XXX	
		Upland hydrologic function	X	XXX	
		Nutrient cycling	X	XXX	
		Stream flow regime	X	XXX	Yes
		Stream / wetland hydrologic function	X	XXX	
		Groundwater dynamics		XXX	
		Cave soil quality	XXX	X	
		Cave hydrologic regime	XXX	X	Yes
Water quality		SEE WATER QUALITY TABLE 36	XXX	XXX	
Disturbance regimes		Fire regimes	XX	XXX	
		Extreme climatic events	XXX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	XX	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	X	XXX	
	At-risk species or communities	Status of at-risk species – amphibian populations		XX	
		Status of at-risk species – bat populations	XXX	XX	
		Status of at-risk species – Mexican spotted owl populations			
		Status of at-risk species – peregrine falcon populations		XXX	
		Status of at-risk species – other TES vertebrate populations (spp. vary by park)			
		Status of at-risk species – TES plant populations (spp. vary by park)		XXX	
		Status of at-risk communities – riparian-obligate birds		XXX	
		Status of at-risk communities – sagebrush-obligate birds		XX	
		Status of at-risk communities – pinyon-juniper-obligate birds		XX	
		Status of at-risk communities – native fish communities		XX	
		Status of at-risk communities – native grassland / meadow plant communities		XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities		XXX	

Table 20 continued.

Category		VITAL SIGN	Priority		Currently Monitored?
			TICA	NCPN	
Ecosystem characteristics					
Biotic integrity	At-risk species or communities	Status of at-risk / focal communities – riparian / wetland plant communities	X	XXX	
	Focal species or communities	Status of focal communities – biological soil crusts		XXX	
		Status of focal communities – aquatic macroinvertebrates		XXX	
		Status of focal / unique communities – spring, seep, & hanging-garden communities		XXX	
	Endemic species or unique communities	Status of unique communities – relict plant communities		X	
		Status of unique communities – cave cricket communities	XXX	X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition		XX	
		Park insularization	XX	XXX	
		Landscape fragmentation and connectivity	XX	XXX	
Other vital-sign categories					
Stressors		Park use by visitors	XXX	XXX	Yes
		Invasive exotic plants	XXX	XXX	Yes
		Invasive, exotic, and/or feral animals (exotic cave organisms)	XX	XX	
		Occurrence patterns of novel diseases / pathogens	X	X	
		Permitted consumptive / extractive activities on park lands		X	
		Park administration and operations	XX	XX	
		Changes in stream hydrologic regimes due to surface-water diversions	X	XX	
		Changes in stream hydrologic regimes due to large reservoirs		XX	
		Changes in groundwater hydrologic regimes due to groundwater extraction		XX	
		Adjacent / upstream land-use activities	XXX	XXX	
		Non-compliant uses on park lands		XX	
Other natural resource values		Status of paleontological resources		X	
		Status of natural night skies		XX	
		Status of natural cave soundscapes	XXX	XX	
		Status of cave formations	XXX	X	Yes

Disturbance regimes. Extreme climatic events are disturbances that affect ecosystems both within and external to the cave. As a consequence, monitoring for such events is a high priority for Timpanogos Cave. The status of natural fire regimes and insect / disease outbreaks in forests also are important vital signs for the park.

Biotic integrity. Highest priority biotic vital signs for the park are two associated with the cave ecosystem – the status of bat populations and the status of cave cricket communities. Relative to these, biotic vital signs associated with external ecosystems are low priority.

Landscape-level patterns. Land-cover and land-use patterns, largely because of their potential for affecting cave hydrology and water quality, are high-priority vital signs for the park. Because of the park's small size (98 ha) and high perimeter:area ratio (40:1), degree of park insularization, and landscape fragmentation and connectivity also have been identified as important vital signs for Timpanogos Cave.

Stressors. Three vital signs associated with pro-active monitoring of anthropogenic stressors have been identified by Timpanogos Cave as high-priority monitoring needs because of their potential impacts on park resources. These include park visitor-use patterns, invasive exotic plants, and adjacent / upstream land-use activities. Visitor-use patterns and invasive exotic plants both are monitored currently, but the adequacy of this monitoring for meeting vital-sign needs will be reevaluated during the Phase III process. Park administration and operations, and invasive / exotic animals (emphasizing exotic cave organisms) also are important vital signs for the park.

Other natural resource values. The status of natural cave soundscapes and cave geologic formations both are high-priority monitoring needs for the park. Relative to other parks in the network, altered soundscapes currently have the greatest potential for causing biotic impacts at Timpanogos Cave because of the importance of acoustic conditions for bats.

Zion National Park

Zion National Park has identified 33 high-priority vital signs (Table 21). Eighteen of these currently are monitored to one degree or another. The adequacy of existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process.

Climatic conditions. Precipitation patterns and temperature patterns are high-priority vital signs for Zion because of their significance as drivers of ecosystem variability and change. Both currently are monitored in conjunction with the National Weather Service Cooperative Network and via automated RAWS fire-weather stations. Wind patterns – also an important vital sign for Zion due to effects on multiple ecological processes (particularly fire behaviour) – also are monitored via automated RAWS fire-weather stations.

Air quality. Zion is classified as a Class I Area under the Clean Air Act. As a consequence, all vital signs related to air quality are high priority. Ozone and particulate levels (visibility measure) both are monitored at Zion. As discussed in the network overview, modeling indicates the potential for a “hot spot” of N deposition in the vicinity of Zion due to upwind emissions from Las Vegas, Nevada, and St. George, Utah (Fenn et al. 2003a). The adequacy for Zion of current wet and dry deposition monitoring at Bryce Canyon and the Grand Canyon, respectively, will be assessed during the Phase III process.

Soil, water, and nutrient dynamics. Upland soil / site stability, upland hydrologic function, and nutrient cycling all are high-priority vital signs for Zion because of their significance for the sustainability of upland ecosystems and because of their sensitivity to visitor-use impacts and natural disturbances such as fire. Likewise, stream flow regime and stream hydrologic function are high-priority vital signs because of their significance for the sustainability of riparian and aquatic ecosystems associated with the Virgin River and other important perennial and intermittent drainages in the park. Zion is well known for the abundance and diversity of groundwater-dependent ecosystems in the park (e.g., hanging gardens). As a consequence, groundwater dynamics also is a high-priority monitoring need for the park.

Water quality. Water quality is a high-priority component of vital-signs monitoring at Zion. See the water-quality discussion (below) for details.

Table 21. Vital signs for Zion National Park (excluding water quality). Within the Priority columns, Xs indicate relative priority (high-medium-low) for Zion and across the NCPN as a whole. Vital signs that are currently monitored are indicated by "Yes" or, in the case of Air Quality vital signs, by the location of the nearest monitoring location. In all cases, the adequacy of current monitoring will be reevaluated in relation to vital-signs needs. See Appendix B for potential measures associated with vital signs.

Category		**VITAL SIGN**	**Priority**		**Currently Monitored?**
			ZION	**NCPN**	
Ecosystem characteristics					
Climatic conditions		Precipitation patterns	XXX	XXX	Yes
		Air temperature patterns	XXX	XXX	Yes
		Wind patterns	XX	XX	Yes
Air quality		Atmospheric deposition	XXX	XXX	BRCA (wet dep., 80 km NE); GRCA (dry dep., 160 km SE)
		Visibility	XXX	XXX	ZION
		Tropospheric ozone levels	XXX	XXX	ZION
Soil, water, and nutrient dynamics		Upland soil / site stability	XXX	XXX	
		Upland hydrologic function	XXX	XXX	
		Nutrient cycling	XXX	XXX	
		Stream flow regime	XXX	XXX	Yes
		Stream / wetland hydrologic function	XXX	XXX	
		Groundwater dynamics	XXX	XXX	
Water quality		SEE WATER QUALITY TABLE 37	XXX	XXX	Yes
Disturbance regimes		Fire regimes	XXX	XXX	Yes
		Extreme climatic events	XXX	XXX	Yes
		Insect / disease outbreaks in forests and woodlands	XX	XX	
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities	XXX	XXX	Yes
	At-risk species or communities	Status of at-risk species – amphibian populations	X	XX	
		Status of at-risk species – bat populations	XX	XX	
		Status of at-risk species – Mexican spotted owl populations	XXX	XXX	Yes
		Status of at-risk species – peregrine falcon populations	XX		Yes
		Status of at-risk species – Virgin spinedace (*Lepidomeda mollispinis*) populations	XXX		Yes
		Status of at-risk species – desert tortoise populations and habitat conditions	XXX		Yes
		Status of at-risk species – *Astragalus eremiticus* var. *ampullarioides* (Shivwits milkvetch) populations and habitat conditions	XXX	XXX	Yes
		Status of at-risk communities – riparian-obligate birds	XXX	XXX	Yes
		Status of at-risk communities – sagebrush-obligate birds		XX	
		Status of at-risk communities – pinyon-juniper-obligate birds	XX	XX	
		Status of at-risk communities – native fish communities	XXX	XX	Yes
		Status of at-risk communities – native grassland / meadow plant communities	XX	XXX	
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities	X	XXX	
		Status of at-risk / focal communities – riparian / wetland plant communities	XXX	XXX	
	Focal species or communities	Status of focal communities – biological soil crusts	XXX	XXX	
		Status of focal communities – aquatic macroinvertebrates	XXX	XXX	
		Status of focal / unique communities – spring, seep, & hanging-garden communities	XXX	XXX	Yes
	Endemic species or unique communities	Status of rare / endemic plant populations – multiple species	X	XXX	
		Status of unique communities – relict plant communities	XX	X	
		Status of unique communities – tinaja / waterpocket communities	XX	X	
Landscape-level patterns		Land cover	XXX	XXX	
		Land use	XXX	XXX	
		Land condition	XX	XX	

Table 21 continued.

Category	VITAL SIGN	Priority		Currently Monitored?
		ZION	NCPN	
Ecosystem characteristics				
Landscape-level patterns	Park insularization	XXX	XXX	
	Landscape fragmentation and connectivity	XXX	XXX	
Other vital-sign categories				
Stressors	Park use by visitors	XXX	XXX	Yes
	Invasive exotic plants	XXX	XXX	
	Invasive, exotic, and/or feral animals	X	XX	
	Occurrence patterns of novel diseases / pathogens	X	X	
	Permitted consumptive / extractive activities on park lands		X	
	Park administration and operations	XX	XX	
	Changes in stream hydrologic regimes due to surface-water diversions	XX	XX	
	Changes in stream hydrologic regimes due to large reservoirs		XX	
	Changes in groundwater hydrologic regimes due to groundwater extraction	XX	XX	
	Adjacent / upstream land-use activities	XXX	XXX	
	Non-compliant uses on park lands	XXX	XX	
Other natural resource values	Status of paleontological resources	X	X	
	Status of natural night skies	XX	XX	
	Status of natural soundscapes	XX	XX	

Disturbance regimes. Other than flow events (which are capture in hydrologic regime, above), wildfire and extreme climatic events are the predominant natural disturbances at Zion. As a consequence, these have been identified as high-priority vital signs. The occurrence of insect / disease outbreaks in woodland and forest ecosystems also is an important vital sign for Zion.

Biotic integrity. The status of predominant upland plant communities and riparian / wetland plant communities both are high-priority vital signs for Zion. Vegetation monitoring at Zion is expected to be oriented towards the assessment of dynamics in relation to natural wildfire, restoration of upland fire regimes and Virgin River hydrologic regimes, and climatic fluctuations. Integrated vegetation monitoring at Zion and Cedar Breaks National Monument (see above) also has the potential to provide information concerning climate-vegetation relationships over a 2000-m elevational gradient. The existence of this steep elevational gradient over a 50-km horizontal distance may provide important opportunities for leveraging financial resources to investigate questions pertaining to global change. Two regionally at-risk community types are high-priority vital signs for the park. These are native fish communities and riparian-obligate bird communities. Two other at-risk communities also are important vital signs – native grassland / meadow plant communities and pinyon-juniper-obligate bird communities. Zion has identified several at-risk species or species populations as high-priority vital signs. These include Mexican spotted owl populations (federally threatened), Virgin spinedace populations (managed under conservation agreement), desert tortoise populations (federally threatened), and Shivwits milkvetch populations (federally endangered). Bat populations and peregrine falcon populations also are important vital signs in the at-risk category. Because of their functional significance for Zion ecosystems and landscapes, three types of focal communities have been identified as high-priority vital signs – biological soil crust communities; aquatic macroinvertebrate communities; and spring, seep, and hanging-garden communities. Zion supports several upland communities / ecosystems that are considered to be land-use relicts or climatic relicts. The condition of these systems is an important vital sign for the park because of their unique nature and restricted extent. The status of unique tinaja communities / ecosystems also is an important vital sign for the park.

Landscape-level patterns. Zion has significant urban-interface issues, including encroaching development west, north and east of the park, as well as substantial private in-holdings (see Appendix A, Evenden et al. 2002). Over 40 percent of the park's boundary is shared with private land owners (Table 20, Evenden et al. 2002). Thus four vital signs associated with broad-scale landscape patterns are high-priority monitoring needs for Zion. These include land cover, land use, degree of park insularization, and landscape fragmentation and connectivity. The status of land-condition patterns also is an important vital sign for the park.

Stressors. Four vital signs associated with pro-active monitoring of anthropogenic stressors potentially impacting park resources are high-priority monitoring needs for the park. These include visitor-use patterns, invasive exotic plants, adjacent land-use activities, and non-compliant uses on park lands. Of these, only visitor-use patterns currently are monitored. Existing monitoring will be reevaluated in relation to vital-sign needs during the Phase III process. Other important vital signs include the status of invasive, exotic, and/or feral animals (an urban-interface issue); park administration and operations; changes in hydrologic regimes due to surface-water diversions; and changes in groundwater hydrologic regimes due to groundwater extraction.

Other natural resource values. The status of natural night skies and soundscapes also are important vital signs for the park. The status of paleontological resources is a vital sign for Zion, but it is low priority relative to ecologically oriented vital signs.

Water Quality and Quantity Vital Signs

This section focuses on vital signs pertaining to water quality and, to a lesser degree, water quantity. Water quality is an important ecosystem characteristic that is integrated in the NCPN vital-signs framework (Table 1) that is applied throughout this report. Ecosystem- and watershed-based perspectives indicate numerous relationships among vital signs discussed in the preceding section and water-quality vital signs discussed below. For example, upland soil / site stability, upland hydrologic regimes, and broad-scale patterns of land cover and land use all have important implications for various measures of water quality. Conversely, water quality can strongly affect the condition of at-risk aquatic biota including amphibian populations and native fish communities. Water quality is a key characteristic that partially describes the condition of focal ecosystems such as springs and seeps as well as unique ecosystems such as hanging gardens and tinajas.

Water *quality* is the specific focus of the vital-signs discussion in this section. Water quality (as opposed to quantity) is emphasized here because NPS funding was obtained specifically to document the condition of park waters under the Clean Water Act, and because water quality is recognized as an important factor in ecosystem function.

Water *quantity*, because of its effects on constituent concentrations, is an inseparable aspect of water quality. Though an effort will be made to collect flow or stage information along with all water quality samples in order to effectively interpret the results, this is not intended as a substitute for regular water-flow monitoring. Stream, wetland, and groundwater hydrologic regimes are explicitly addressed above in the broader vital-sign discussion under the category pertaining to soil, water, and nutrient dynamics. Stream flow has significant attributes that will not be captured by measurements taken in conjunction with relatively infrequent water-quality sampling. Most significant among those attributes are seasonal flood peaks and diurnal fluctuations. In most of the water-based systems in this network, the hydrologic regime (i.e., the timing, frequency, magnitude, and duration of flow) will far exceed water *quality* as a driver of ecosystem processes.

This section begins with an overview of information sources and activities that supported the identification of water-quality vital signs. Following this overview, there is a discussion of networkwide water-quality issues pertaining to vital signs selection. The remainder of this section consists of park-by-park descriptions of water-quality vital signs, including the presentation of park-specific tables.

General Approach to the Selection of Water-Quality Vital Signs

The servicewide guidance for development of water quality vital signs (NPS-WRD 2001) identified several potential approaches to vital-sign selection. NCPN water-quality vital signs were identified on the basis of park scoping sessions (including two water-quality workshops), professional input provided via the web-based Delphi survey (see Appendix A), and a preliminary assessment of water quality data compiled in a database developed by the U.S. Geological Survey Water Resources Discipline (USGS-BRD).

The basis for this approach stems from several sources including Kunkle and colleagues (1987), MacDonald (1991), and Davis and colleagues (2001). These sources highlight several approaches for identifying appropriate indicators of water quality. One approach presents water quality parameters that are vulnerable to alteration from various sources of contamination or land management practices. Another approach is to identify vital signs that are particularly useful for indicating the health of particular types of water resources (i.e., streams, lakes, seeps, etc.). A third approach is to identify water quality indicators for the protection of designated uses (the types of uses assigned by states to each particular water body or stream, and protected by specific numeric standards). All have been found to be useful in the effort to identify water quality vital signs in the NCPN.

Vital Signs Selection in Relation to Park, Network and Servicewide Goals

During a NCPN water quality workshop held in June 2003, participants agreed that legal mandates, e.g. the Clean Water Act, were the most important to address in the selection of vital signs and a monitoring effort. There was also interest in focusing on long-term monitoring needs as opposed to short-term management needs. The group agreed that the overall NCPN network goals for water-quality and quantity monitoring are:

1. Collect, analyze and interpret data to support management in relation to 303(d) listings of waters,
2. Collect, analyze and interpret data to support management of threatened or otherwise special waters, using state standards developed under the Clean Water Act, and
3. Identify data needs, including inventory requirements, in relation to the status and trends of selected indicators for the condition of park ecosystems. These data can provide early warning signs to provide resource managers with the ability to mitigate problems and improve park resources.

Consistent with NPS Water Resource Division (NPS-WRD) recommendations, these goals are ordered to acknowledge that issues associated with legal mandates clearly are the first priority for water-quality monitoring.

Phases I and II

The major actions taken by the NCPN and other parties as part of Phases I and II were:

- Developed a servicewide Program Guidance draft document (NPS-WRD),
- Developed a Baseline Water Quality Inventory and Analysis horizon draft document (NPS-WRD; a compilation and preliminary analysis of data in the STORET database)
- Distributed and analyzed a questionnaire soliciting input from park staff regarding their significant waters and water quality issues (Colorado State University),
- Conducted park scoping visits to discuss water quality concerns and review available literature (Colorado State University),
- Established contacts with managers of adjacent lands and state water quality agencies (Colorado State University),
- Identified all waters in NCPN parks that are included on the state's 303d lists of waters not meeting standards (Colorado State University),
- Conducted a scoping workshop for NCPN parks in June 2002 that established priorities and goals for water quality monitoring (NCPN),
- Identified water quality issues in each park (NCPN, see Appendices O and P in the NCPN Phase I report),
- Included water quality vital signs in the Delphi process used to develop broader natural resource vital signs (NCPN),
- Assembled available data from STORET, legacy STORET and NWIS, and developed a relational water-quality database conducive to analysis (U.S. Geological Survey, Water Resources Discipline; USGS-WRD),
- Conducted preliminary analyses of data for areas of concern and exceedences of state standards (USGS-WRD); (This was done both prior to the workshop and with real-time data analysis during the workshop),
- Conducted a Water Quality Vital Signs Workshop in April 2003, and
- Provided Workshop participants with numeric and graphical data summaries for each park.

Early efforts as part of Phase I focused on the identification of management and scientific issues that were presented in Appendices O and P in the NCPN Phase I report (Evenden et al. 2002). Water quality experts from Colorado State University facilitated these efforts. Site visits to the parks for discussions with park managers, resource managers, maintenance staff, and reviews of park files were found to be particularly useful. Summaries of issues facing parks and descriptions of park water resources were developed, prepared and incorporated into the Phase I report with the assistance of Western State College in Gunnison, Colorado.

Database Development

Work on Phase II began with the development of a water-quality database for all NCPN parks by the USGS-WRD office in Grand Junction, Colorado. This database incorporates more than one million data records from approximately 20 local, state, and Federal sources, and have been compiled, screened, and merged into a single relational Access database. It combines all available data through December 2002 from two EPA water-quality databases – Legacy STORET and modern STORET – and the USGS National Water and Information System (NWIS) for sites located in all 16 parks and surrounding buffer areas. Additional available data from selected parks (e.g. ZION) were also incorporated into the database. STORET is the EPAs STOrage and RETrieval database used for water quality data storage for the nation. The USGS-NCPN database is intended as a data analysis tool and incorporates several features to improve its utility over the source databases:

- a database structure conducive to multiple levels of analysis,
- coding for sites located inside and outside of each park,
- screening for unreasonable values and quarantine of suspect data,
- a means for incorporating "less than detectable" in statistical analysis,
- a means for reconciling differences between Legacy STORET parameter codes and modern STORET,
- designation of parameter groups, source matrices and sample types,
- optimization of selected constituents to maximize data utility,
- selected standard queries, forms and modules designed to aid data retrieval, analysis and interpretation, and
- GIS interface for utilizing data within a GIS environment to facilitate spatial analysis on a park or network level.

The USGS-WRD participated in the vital signs workshop with real-time data queries, using the database to screen for state standards, investigate parameters of particular concern, and identify data-rich and data-poor sites.

Use of the Delphi Process to Identify Water Quality Vital Signs

Water quality vital signs were included in the NCPNs Delphi process, though park-based scoping and the water-quality component of the vital-signs workshop were the primary approaches used to identify water-quality vital signs. The Delphi process focused on interactions among all ecosystem elements, whereas the water-quality workshop focused on traditional suites of parameters together with state water quality standards. Among workshop attendees, there was general agreement between the results of the Delphi process and the discussions of the more traditional water quality measures. In particular, the nation-wide core parameters ranked among the highest in the Delphi ranking process. One very notable result of the Delphi process and subsequent vital-sign evaluation exercises was that stream flow was among the highest ranking of any vital sign (see Appendix Table A-12). This is recognition that stream hydrologic regime is a major factor controlling the structure and functioning of riparian and aquatic ecosystems.

Vital Signs Workshop

In addition to park-based scoping, an essential step toward the identification of water quality vital signs was a workshop conducted on April 10th and 11th, 2003 in Moab, Utah. Twenty-three participants including water quality-monitoring experts, NCPN staff, and park staff met to identify key waters, tentative sample-site locations, vital signs and measures to be monitored, and potential sampling schedules. Also present were the database team from the USGS-WRD and a water-planning specialist from Western State College, with several years of experience with water issues in NCPN parks. A list of participants and minutes from the workshop are provided in Appendix C. Park-specific and network-wide discussions that follow represent the results of this workshop, and will provide the framework for the monitoring design to be prepared during Phase III.

Existing Monitoring

Two groups of parks have established monitoring efforts, the Southeast Utah Group of parks and a joint effort in Black Canyon of the Gunnison NP and Curecanti NRA. The Southeast Utah Group has been monitoring its water quality and quantity since the early 1990s. Black Canyon of the Gunnison NP and Curecanti NRA are monitoring their waters in an effort to attain anti-degradation and Outstanding National Resource Water status for approximately 21 water sources. These existing monitoring programs provide examples that may inform the design of water-quality monitoring in other NCPN units.

Water Quality Vital Signs

Networkwide Water Quality Themes and Observations

Some water quality constituents are considered a concern at several parks. While these have been considered as possible network core parameters in addition to the servicewide core parameters, none were found to be pervasive enough to warrant such a designation. Some water-quality parameters of widespread concern across the NCPN are discussed below.

Selenium is a contaminant throughout much of the Colorado River basin with elevated levels due to irrigation practices and development (Butler and Lieb 2002). Natural background levels are high and associated with particular soil types and geological features such as Mancos shale. Discussions in the workshop concluded that monitoring of selenium would be adequately addressed by (1) including selenium in trace element analysis for the Colorado River and major tributaries, and (2) further studies by the USGS and others agencies.

Pesticides can also be problematic along major rivers in some of the network parks such as Dinosaur NM and Canyonlands NP. While valid, and interest in monitoring of pesticides is noted in the park-by-park discussions that follow, this concern will have to be addressed outside of the NCPN monitoring program due to the very high cost of laboratory analysis for pesticides.

Common water features in NCPN parks are springs, seeps, hanging gardens, and tinajas. These sources of water are critical to flora and fauna, and are aesthetically important to park visitors and staff. Monitoring is sometimes difficult because the individual water sources, though often diminutive, can be numerous and can have diffuse points of discharge that are difficult to sample. A network approach applicable to many springs is to rotate sampling from year-to-year among several springs, as is currently done in the Southeast Utah Group of parks. In addition, a NCPN effort to specifically inventory and monitor seeps and springs is planned and will be prefaced by a design of a program for the network. Though this will have a broader focus than just water quality and quantity, it will also include an attempt to measure discharge, and will likely include site visits that present an opportunity to collect water quality samples.

Chlorophyll and carbon were listed as vital signs that may be considered for inclusion in a monitoring program. Chlorophyll is monitored only at Curecanti. This parameter is effective in relaying information about eutrophication levels in reservoirs, lakes, ponds and even streams and has been historically sampled at Curecanti. At present, chlorophyll monitoring at other parks is not recommended since there is little historical information. None of the parks recommended, or are currently monitoring, forms of organic carbon. Monitoring this parameter in its various forms (benthic organic matter, total organic matter, coarse organic matter, dissolved organic matter etc.), is very important in describing the structure and function of lotic systems, and can relay information about changes in an aquatic system. However, these measures are not necessarily easy, convenient or inexpensive. Coupled with the fact that little historical data are available, measurement of this parameter is best left to special studies.

Park Water Quality Vital Signs

A presentation of water quality vital signs and measures follows for each park unit in the network. These are a result of the information gathering and discussion process described above, and will be the basis for the monitoring design conducted in Phase III. Some modification may occur as the design proceeds and costs and logistics are evaluated.

To reduce wordiness, water quality parameters are frequently discussed and presented in groups such as "major ions" or "nutrients." These groupings (Table 22) are commonly used to describe various suites of laboratory analysis and offer a practical way to discuss the myriad of possible parameters. In some cases, specific parameters are identified as important. Where this occurs, one of the tasks under Phase III will be to ensure that laboratory accuracy and detection limits, and sampling frequency are adequate to determine if standards are met.

Table 22. Water quality parameter groups as used in park water quality vital sign tables for NCPN parks.

PARAMETER GROUP	Curecanti NRA/Black Canyon NP with US Geological Survey*	State Utah Division of Water Quality Laboratory**and All Other NCPN Parks
Core Parameters	Dissolved Oxygen pH Conductivity Water Temperature Flow	Dissolved Oxygen pH Specific Conductance (in lab) Water Temperature Flow
Nutrients	Unionized Ammonia (calculated), Dissolved and Total Ammonia, Nitrate+Nitrite as N, Nitrate as N, Total Phosphorus, Ortho-phosphorus, and Dissolved and Total Nitrogen	Total Phosphorus, Ammonia Dissolved, Total Phosphorus (ortho), Dissolved Nitrate+Nitrite
Trace Elements	Dissolved Cadmium, Copper, Lead, Manganese, Silver, and Zinc	Dissolved Aluminum, Arsenic, Barium, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Selenium, Silver and Zinc

Table 22 continued.

PARAMETER GROUP	Curecanti NRA/Black Canyon NP with US Geological Survey*	State Utah Division of Water Quality Laboratory**and All Other NCPN Parks
Major Ions	Calcium (mg/L) Magnesium (mg/L)	Chloride, Sulfate, Total Alkalinity, Total Dissolved Solids, Total Suspended Solids, Carbonate, Bicarbonate, Hydroxide, Carbon Dioxide, Calcium, Sodium, Magnesium, Potassium, Total Hardness
Microorganisms	E. coli	Fecal coliform
Macroinvertebrates	Macroinvertebrates	Macroinvertebrates
Carbon	Carbon	Carbon
Organics	Organics (can be many)	Organics (can be many)
Other	Turbidity, Secchi Disc, Chlorophyll a	Turbidity (in lab)

* These parks have a current monitoring program and send their samples to the USGS National Water Quality Lab. Curecanti and Black Canyon utilize the USGS protocols for collection of water samples. The USGS National Laboratory is NELAP certified (i.e. has an established and strict QA/QC program).
** The Southeast Utah Group and Zion cooperate with the State of Utah Division of Water Quality. The parks collect the samples and the state analyzes them. Richard Denton with the State of Utah notes that his lab must update their QA/QC protocol. SEUG has documented its collection protocols. Zion began collection in 2003. The Phase III report will clarify protocols and QA/QC protocols for each entity that analyzes samples.

Arches National Park

Significant natural water bodies include Courthouse Wash, Freshwater Canyon, Sleepy Hollow Wash, Seven Mile Canyon, Salt Valley Wash, Salt Wash, Salt Spring, Willow Spring and Lost Spring Canyon. These water sources represent springs and ephemeral and intermittent streams. The Colorado River, which is not within the park boundaries, flows to the southwest along the southeastern boundary of the park. Management issues associated with park water quality include changes in stream flows associated with adjacent development, recreational impacts, trespass grazing, and mining efforts adjacent to the park. The Arches monitoring program is geared toward measuring parameters that serve as indicators, and since the State of Utah analyzes numerous parameters, the park realizes the benefits of getting a large amount of information per sample.

Currently, Arches has a water quality-monitoring program that is combined with the 3 other parks in the Southeast Utah Group of parks. Park personnel collect water samples that are then analyzed by the State of Utah laboratory and uploaded into STORET. The Arches water quality program was initiated in the late 1980s and was reevaluated in 1994 (National Park Service 1994). Most recently, the park uses a 3-year rotational system (1 year on, and 2 years off) for sampling water within the Southeast Utah Group of parks. At Arches the park monitors the quality and quantity of water at Courthouse Wash, Freshwater Spring, Sleepy Hollow, Willow Spring, and Salt Wash. Every month they monitor approximately 3 sites at a given park. They monitor aquatic invertebrates on a quarterly basis in the field, and microorganisms on a monthly basis in-house.

Table 23 provides sites and parameters that are measured at Arches. The park monitors nutrients, trace elements, major ions, core parameters, macroinvertebrates and fecal coliform bacteria. Monitoring of pesticides is desired, but costs are prohibitive. In addition to the water quality parameters, the Utah State Water Resources Division has funded 3 years of study at 4 springs to evaluate quantity issues related to development adjacent to the park.

Table 23. Water quality vital signs for Arches National Park.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source					
	Courthouse Wash	Freshwater Spring	Sleepy Hollow	Willow Spring	Salt Wash	Tinajas
Core Field Parameters	C-UT	C-UT	C-UT	C-UT	C-UT	F
Stream flow	C-NPS	C-NPS	C-NPS	C-NPS	C-NPS	
Nutrients	C-UT	C-UT	C-UT	C-UT	C-UT	F
Trace Elements	C-UT	C-UT	C-UT	C-UT	C-UT	F
Major Ions	C-UT	C-UT	C-UT	C-UT	C-UT	F
Microorganisms	C-UT	C-UT	C-UT	C-UT	C-UT	
Macroinvertebrates	C-UT	C-UT	C-UT	C-UT	C-UT	F
Chlorophyll						
Carbon						
Organics (Pesticides)						
Turbidity						
Priority	H	H	H	H	H	M
Schedule	Rotation of 12 samples/yr at three sites, EACH SITE SAMPLED 1YR-ON, 2YR-OFF, macroinvertebrates are monitored quarterly on similar rotation, microorganisms monthly on similar rotation.					
Logistics	A	A	A	A	A	A-D
R = RECOMMENDED NEW MONITORING SITE, C = CURRENT MONITORING TO CONTINUE, F = SITES FOR FUTURE CONSIDERATION, PRIORITY: H = HIGH, M = MEDIUM, L = LOW LOGISTICS: A = EASY ACCESS, D = DIFFICULT ACCESS						

Tinajas exist and are vulnerable to contamination from visitor activities and atmospheric sources. They are considered for future monitoring.

One of the concerns with the state program is documentation and coordination of a quality control and quality assurance (QA/QC) program with the park's methodology. A benefit of the vital signs program will be the development of a network QA/QC protocol for collection and analysis of water samples that will provide further guidance and substance to the park's monitoring program.

Black Canyon of the Gunnison National Park

Canyon walls of Precambrian rock above the Gunnison River define Black Canyon of the Gunnison National Park. Three upstream dams, part of the Colorado River Water Storage Project and referred to as the Aspinall Unit, have altered this significant water body. The Gunnison Tunnel, which diverts water to the Uncompahgre Water Valley Users Association, also alters the system. The combined issues of water rights quantification and an altered hydrologic regime are a major management concern in the region.

Water quality in the Gunnison River below the Aspinall Unit is exceptional and is presently being monitored for status as an Outstanding National Resource Water (ONWR). Table 24 presents the parameters that are currently measured.

Table 24. Water quality vital signs for Black Canyon of the Gunnison National Park.

VITAL SIGN	Water Source	
(See Table 22 for individual parameters in each group)	Gunnison River	Red Rock Creek
Core Field Parameters	C-NPS	C-USGS
Stream flow	C- NPS	C-USGS
Nutrients	C- NPS	C-USGS
Trace Elements	C- NPS	C-USGS
Major Ions	C- NPS	C-USGS
Microorganisms	C- NPS	C-USGS
Macroinvertebrates		C-USGS
Chlorophyll		
Carbon		
Organics (Pesticides)		
Turbidity	C- NPS	C-USGS
Priority	H	H
Schedule	7 samples/yr	7 samples/yr
Logistics	A	A

R = Recommended New Monitoring Site, C = Current Monitoring to Continue,
F = Sites for Future Consideration
Priority: H = High, M = Medium, L = Low,
Logistics: A = Easy Access, D = Difficult Access

At present, Red Rock Creek is monitored for a suite of parameters and is also part of a study to assess Black Canyon and Curecanti waters for ONRW status. Protected uses for Red Rock Creek are designated as Aquatic Life 2, Recreation 2, but has relatively high *E. coli* bacteria, ammonia and selenium levels (see Appendix D for definitions of protected-use designations). These levels however, do not exceed the current designation. Agricultural return flows from the Bostwick Park area to the south of Black Canyon likely contribute to the contamination of the creek. Red Rock Creek is essentially the end of an irrigation ditch with substantial ground water inputs farther downstream. Because of historic private land issues surrounding Red Rock Creek, the area has not been opened to the public. Opening of this area to the public in the foreseeable future may change the potential for primary contact recreation and therefore the designation to Recreation 1. The creek would then exceed the standard for primary contact recreation. Since the contamination most likely emanates from outside of the park, this management issue may require assistance through the Colorado State 303(d) listing process.

Curecanti and Black Canyon have a water quality program geared towards compliance with both the Clean Water Act and the Government Performance and Results Act of 1993 (GPRA). In Colorado, anti-degradation classification for these waters requires that the core parameters, E. coli, unionized ammonia, nitrate-nitrite, Cd, Cu, Pb, Mn, Se, Ag, and Zn be measured. The park also measures other parameters such as total phosphorus and turbidity. No other parameters were discussed for monitoring during the workshop.

Bryce Canyon National Park

Springs and short stream segments occur in two geologic settings at Bryce Canyon NP, on top of the plateau and below the escarpment. Though the cap rock of the plateau is porous, there are few small springs or wetlands. Dave's Hollow and the Podunk Creek wetland are examples of water bodies on top of the plateau, together with the wetland at the park's water supply well located approximately two miles east of the rest of the park. Most of the park's springs occur at the base of the escarpment that the park is known for, at the contact between the Claron formation and the less permeable layers below. While springs here are located inside of the park, they have only a short discharge flowing out of the park across the eastern boundary. Yellow Springs and nearby Sheep Creek Springs are the largest springs, discharging as much as 200 gpm, while most of the other springs discharge from 5 to 30 gpm.

The most readily observed impact to the springs is from permitted trailing of livestock through the park and frequent occurrences of trespass grazing. Furthermore, the Tropic ditch, a privately owned water conveyance that flows through the park, serves as a vector for weed introduction. This unlined ditch provides a major source of irrigation water for farmers in the town of Tropic and could be recharging springs in that area of the park.

There is also the potential for developing coal bed methane south and east of the park. This could contaminate the Navajo sandstone aquifer by potentially discharging large amounts of wastewater. The park is justifiably concerned, as it may eventually need to drill into the Navajo sandstone to acquire water for park use. Wastewater disposal within the park occurs on the rim and could potentially impact spring water quality, however the infrastructure has been newly lined and is working well.

None of the park waters are known to have water quality problems and none are being monitored at this time.

Table 25. Water quality vital signs for Bryce Canyon National Park.

VITAL SIGN (See Table 22 for individual parameters in each group)	WATER SOURCE			
	Yellow Creek and Sheep Creek	Other Springs Below Rim Water Canyon, Cope, Campbell, Right Fork, Iron, Lonely, & Riggs	Podunk Creek Wetland	Dave's Hollow
Core Field Parameters	R	R	F	F
Stream flow	R	R		
Nutrients	R	R	F	F
Trace Elements				F
Major Ions	R	R	F	F
Microorganisms				
Macroinvertebrates	C-UT	R	F	
Chlorophyll				
Carbon				
Organics (Pesticides)				
Turbidity	R	R	F	F
Priority	High	High	Medium	Low (rely on water supply monitoring)
Schedule	Monthly for 6 months/yr	Monthly for 6 months/year Rotating among 7-8 springs		?
Logistics	Hiking, 5 - 8 hours round trip to individual springs	Hiking, 5 - 8 hours round trip to individual springs. 3 days travel to hike to all of them	Service road, blocked in winter	Easy, except in winter
R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration.				

Yellow and Sheep Creek Springs are a high priority for monitoring core parameters, flow, nutrients, major ions, total dissolved solids, turbidity, and macroinvertebrates. Other springs below the rim (Cope, Water Canyon, Campbell, Right Fork, Iron, Lonely and Riggs springs) are considered as high priority for the same parameters, but at a reduced frequency. Podunk Creek wetland is of medium priority and could be rotated with the other springs. Finally, Dave’s

Hollow is a low priority site though the park would rely on its water supply monitoring to indicate water quality at this site.

Canyonlands National Park

Canyonlands National Park is part of the Southeastern Utah group of parks. As such, water quality monitoring presently occurs and has been discussed under Arches National Park. Resource management issues include reduced quantity in springs related to adjacent development, selenium contamination in the Green and Colorado rivers, pathogen contamination related to recreational and livestock use, increased salinity levels related to oil and gas development, and effluent from upstream municipalities on the Colorado River.

The Green and Colorado Rivers are monitored from April through October on a monthly basis for core parameters, flow, nutrients, trace elements, major ions, total suspended solids, dissolved solids, and turbidity. Pesticide inputs are not monitored due to prohibitive expense. Cave Spring, Little Spring Canyon, 2.4 Mile Loop, Bates-Wilson, Crescent Arch, Peekaboo, and the Maze Overlook are also monitored for the same parameters as springs in Arches. Springs and waters other than the Green and Colorado rivers are sampled on a rotational basis 12 times per year. Three sites are selected and monitored for a year, and then not monitored again for two years. This year (2003) Horseshoe Canyon, Chocolate Drops and the Maze Overlook are being sampled. SEUG considers all of their sites high priority and would like to continue with this monitoring effort that was initiated in the late 1980s.

Tinajas exist and are vulnerable to contamination from visitor activities and atmospheric sources. They are considered for future monitoring.

Table 26. Water quality vital signs for Canyonlands National Park.

VITAL SIGN (See Table 22 for individual parameters in each group)	WATER SOURCE										
	Colorado River*	Green River*	Cave Spring*	Little Spring Canyon*	2.4 Mile Loop*	Bates-Wilson*	Crescent Arch*	Peek-a-boo*	Maze Overlook*[1]	Chocolate Drops*[1]	Horseshoe Canyon*[1]	Tinajas
Core Field Parameters	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	F
Stream flow	C-USGS	C-USGS	C-NPS	C-NPS	C-NPS	C-NPS	C-NPS	C-NPS	C-NPS	C-NPS	C-NPS	
Nutrients	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	F
Trace Elements	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	F
Major Ions	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	F
Microorganisms			C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	
Macro-invertebrates			C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	C-UT	F

Table 26 continued.

VITAL SIGN (See Table 22 for individual parameters in each group)	WATER SOURCE											
	Colorado River*	Green River*	Cave Spring*	Little Spring Canyon*	2.4 Mile Loop*	Bates-Wilson*	Crescent Arch*	Peek-a-boo*	Maze Overlook*[1]	Chocolate Drops*[1]	Horseshoe Canyon*[1]	Tinajas
Carbon												
Organics (Pesticides)	F	F										
Turbidity	C-UT	C-UT										
Priority	H	H	H	H	H	H	H	H	H	H	H	M
Schedule	Monthly (Apr-Oct)	Monthly (Apr-Oct)	Rotation of 12 samples/yr at three sites, each site sampled 1yr-on, 2yr-off, macroinvertebrates monitored quarterly on similar rotation, microorganisms sampled monthly on a similar rotation									
Logistics	D	D	A	A	A	A	A	A	A	A	A	A-D

R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration
Priority: H = High, M = Medium, L = Low,
Logistics: A = Easy Access, D = Difficult Access
* Site is currently monitored as part of the existing program at SEUG, with rotational sites monitored in cooperation with UDWQ for water quality. Microorganisms sampled and analyzed by park staff.
[1] Sites currently being monitored in the rotation.

Capitol Reef National Park

Capitol Reef has five perennial water bodies including the Fremont River, Sulphur Creek, Pleasant Creek, Oak Creek, and Halls Creek. Deep, Polk, Bulberry and Middle Desert Wash creeks, located in the northern portion of the park, are intermittent. Park lands also support hundreds of waterpockets called tinajas. Numerous springs and seeps are also present in the park.

Upstream and downstream of Capitol Reef National Park, the Fremont River has been placed on the 303(d) list for dissolved oxygen, total phosphorus and total dissolved solids.

The Utah Division of Water Quality monitors the Fremont River at Hickman Bridge within the park. This site provides information on the efficacy of the recently adopted Total Maximum Daily Load (TMDL) guidelines for the Fremont River (Millennium Science & Engineering, 2002). A concern is the lack of flow data obtained for this site, as there is no flow gauging station.

The park does not have a current monitoring program but would like to assess the perennial water systems. Preliminary assessment by NCPN staff of the water quality data compiled in the database developed by the USGS reveal high total phosphorus, pH, fecal coliform and turbidity levels. These correspond to the management concerns of livestock trailing and grazing in the park, increased visitor use, and upstream agricultural use, which impacts both water quantity and quality.

The water quality vital signs group recommended that the park continue the joint effort with state monitoring program on the Fremont River and initiate cooperative monitoring on Sulphur, Pleasant, Oak and Halls creeks. These creeks would be monitored for the core parameters, nutrients, turbidity, microorganisms, and macroinvertebrates. Only Sulphur Creek, which is high in total dissolved solids, would be monitored for major ions. Alternatively, since it will not cost the park any more to have trace elements and major ions analyzed at all the sites, the park should incorporate those suites of parameters for the other creeks.

Another management concern is turbidity caused by park irrigation of its orchards and associated impacts to aquatic fauna. The recently instituted TMDL guidelines should improve both turbidity and total phosphorus levels within the park. Pesticide levels associated with their use in park orchards together with those used in upstream agricultural practices are another concern, though cost prohibits an extensive monitoring effort except for possibly in Sulphur Creek.

High fecal coliform levels have been also been documented - these or *E. coli* should be monitored, however, pathogen counts are highly variable and to accurately depict levels, a special study might be needed.

Macroinvertebrates have been monitored extensively at the Fremont River site in Capitol Reef – the park would like to see a similar effort initiated at the Sulphur, Pleasant, Oak, and Halls creeks sites.

Table 27. Water quality vital signs for Capitol Reef National Park

Vital Sign (See Table 22 for individual parameters in each group)	WATER SOURCE								
	Fremont River	Pleasant Creek	Sulphur Creek	Halls Creek	Oak Creek	Deep Creek	Polk & Bulberry Creeks	Middle Desert Wash	Tinajas
Core Field Parameters	C-UT[1]	R	R	R	R	F	F	F	F
Stream flow	C-USGS	R	R	R	R	F	F	F	
Nutrients	C-UT[1]	R	R	R	R				F
Trace Elements	C-UT[1]	R	R	R	R	F	F	F	F
Major Ions	C-UT[1]	R	R	R	R	F	F	F	F
Microorganisms	C-UT[1]	R	R	R	R				
Macroinvertebrates	C-UT[1]	R	R	R	R	F	F	F	F
Chlorophyll									
Carbon									
Organics (Pesticides)	C-UT[1]		R						

Table 27 continued.

Vital Sign (See Table 22 for individual parameters in each group)	WATER SOURCE								
	Fremont River	Pleasant Creek	Sulphur Creek	Halls Creek	Oak Creek	Deep Creek	Polk & Bulberry Creeks	Middle Desert Wash	Tinajas
Turbidity	C-UT[1]	R	R	R	R				
Priority	H	H	H	H	H	M	M	M	M
Schedule	12 samples/ yr	12 samples/ yr	12 samples/ yr	6 samples/ yr	12 samples/ yr	?	?	?	?
Logistics	A	A	A	D	A	D	D	D	Varies

R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration
Priority: H = High, M = Medium, L = Low,
Logistics: A = Easy Access, D = Difficult Access
[1] Continue UDWQ monitoring of the Fremont River at Hickman Bridge

Cedar Breaks National Monument

In spite of being located on the edge of the Markagunt Plateau at over 10,000 feet in elevation and receiving over 35 inches of precipitation a year, Cedar Breaks NM has surprisingly few surface water resources. In certain locations, groundwater perches on slightly less permeable rock layers and issues from springs. None of the springs produce more than a few gallons of water per minute, and flow drops dramatically soon after the year's snow has melted. Alpine Pond supports a small exotic brook trout population where a spring discharges into a slight depression. There is at least one larger spring discharging a few cubic feet per second down in the bottom of the breaks, the rapidly eroding alcove of colorful rock below the rim. Because it is very difficult to access, the flow has not been measured.

Concerns for water quality degradation are few. Wastewater from the park facilities is treated well away from known springs. Spills from commercial use of the park road are a possibility. Trespass cattle and sheep grazing sometimes occurs when fences fail, and the adjacent Dixie National Forest sometimes proposes timber harvests or pesticide treatments near the park. Due to a lack of significant contamination sources, the park could serve as a useful baseline measurement site for springs representative of the general geologic area.

The only park water resource currently monitored is the water supply from Blowhard Spring.

Sampling of Alpine Pond and the springs on the rim is recommended as a low priority and could be easily rotated among sites in nearby Zion NP. The spring located at the bottom of the breaks is of medium priority, and would be considered primarily for inventory. It should be included as part of the network spring and seep inventory, with a comprehensive water quality analysis including core parameters, flow, nutrients, major ions, trace elements, total suspended solids and dissolved solids. Routine monitoring of springs in the breaks would present substantial logistical problems.

Table 28. Water quality vital signs for Cedar Breaks National Monument.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source			
	Blowhard Spring	Springs on the Rim (Shooting Star, Sunset, Unnamed)	Alpine Pond	Springs in the Breaks
Core Field Parameters		R	R	R
Stream flow		R	R	R
Nutrients				R
Trace Elements				R
Major Ions		R	R	R
Microorganisms				
Macroinvertebrates				
Chlorophyll				
Carbon				
Organics (Pesticides)				
Turbidity			R	R
Priority	None	Low	Low	L - Monitoring M - Inventory
Schedule	CAPTURED IN DRINKING WATER MONITORING	ROTATING, 2/YEAR	2/year	Inventory
Logistics	Easy	SHORT EASY HIKE, SUMMER ONLY	Short easy hike, summer only	Difficult hike, 8-12 hours RT

R = Recommended New Monitoring Site, C = Current Monitoring to Continue,
F = Sites for Future Consideration

Colorado National Monument

The monument rises approximately 2,000 feet above the Colorado River, with steep canyons and arroyos supporting ephemeral and intermittent streams, springs, potholes and larger canyon pools. These are critical for wildlife from spring through early summer. Although ephemeral or intermittent, all drainages are important to the park. Flash floods in these canyons threaten housing areas along the park's northeastern boundary. The size of these events indicates that the quantity rather than the quality of water is the main management issue facing the park. Documentation of flash flood potential and education of private landowners downstream of the park is important to the park's management efforts.

Another quantity issue relates to development of domestic and agricultural water supplies in the Glade Park area to the east of the monument. Consumptive use of ground water in this area upstream of the park may reduce flow of springs within the park.

Due to development of rural homes and roads upstream from the monument in the Glade Park area, water pollution from septic tanks, potential spills along the road, road erosion, and grazing are major concerns. Infiltration of contaminants in the Glade Park area can translate into contamination of springs inside the park. Surface runoff from Glade Park also feeds into the park's arroyos. Other sources of contaminants include eroded social trails, roadside runoff, in-park chemical use, and a sewage lagoon located above Fruita Canyon at the western end of the monument. Backcountry hikers and climbers may also impact water quality. Monument staff also expressed concern about aerial pollutants that may impact its water resources.

A synoptic study (Butler 2001) found high selenium levels at several springs. The vital signs group agreed that the levels reflected natural background levels for the area. Other water quality attributes were of minor concern. As such, the park wishes to concentrate on quantity issues and would like to measure flow at 3 sites including No Thoroughfare, Monument, and Fruita canyons. Core parameters would be measured at these sites as well. The park has interest in Red Canyon, but the concern is not as high, since the greatest use is in No Thoroughfare and Monument canyons. The park has no current monitoring program or any resource staff or equipment to conduct monitoring.

Table 29. Water quality vital signs for Colorado National Monument.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source			
	No Thoroughfare Canyon	Monument Canyon	Fruita Canyon	Red Canyon
Core Field Parameters	F	F	F	F
Stream flow	R	R	R	F
Nutrients				
Trace Elements				
Major Ions				
Microorganisms				
Macroinvertebrates				
Chlorophyll				
Carbon				
Organics (Pesticides)				
Turbidity				
Priority	H - Quantity M – Water Quality	H - Quantity M – Water Quality	H - Quantity M – Water Quality	M - Quantity M – Water Quality

Table 29 continued.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source			
	No Thoroughfare Canyon	Monument Canyon	Fruita Canyon	Red Canyon
Schedule	12 samples/ Yr	12 samples/ yr	12 samples/ yr	12 samples/ yr
Logistics	A	A	A	A
R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration Priority: H = High, M = Medium, L = Low Logistics: A = Easy Access, D = Difficult Access				

Curecanti National Recreation Area

Curecanti is a water-based park. Within its boundaries, the Gunnison River is dammed at three locations and form three water bodies - Blue Mesa Reservoir, Morrow Reservoir, and Crystal Reservoir. A stretch of the Gunnison River above these reservoirs flows freely through a floodplain of mature but disturbed narrowleaf cottonwoods and then into a narrow canyon. Major tributaries to the reservoir system include Cebolla Creek, Lake Fork of the Gunnison River, and the Cimarron River. At least 17 other tributaries flow into the reservoirs from the north and south. Threats to future water degradation are primarily due to urban housing and resort development in canyons and along drainages. The park also has a concern with the occurrence and toxicity of polycyclic aromatic hydrocarbons (PAHs) from motorized watercraft, and their impacts on aquatic life in Blue Mesa Reservoir. Since the park has a long history of water quality and quantity monitoring (ca. 1980), park personnel have been able to clearly identify present water resource issues.

The park is currently monitoring 21 sites on the reservoir and in tributaries to seek Outstanding Natural Resource Waters (ONRW) classification, an anti-degradation designation. This effort is combined with a similar effort at BLCA and is geared towards compliance with both the Clean Water Act and GPRA. The park needs credible water quality data to accurately characterize the quality of the water found in the parks. Since 2000, the park has worked with the USGS National Water Quality Lab in Denver and the USGS Water Resource Division-West Slope Sub-district in Grand Junction to collect and analyze data suitable for the ONRW application. Most of the sites reveal good water quality adequate for the anti-degradation designation.

Also in 2000, the park successfully petitioned the State of Colorado to re-classify the designated uses of certain streams from Aquatic Life 2, Recreation 2, Use Protected, based on no data, to the higher level Aquatic Life Cold 1 Class, to be based on the high quality data that the park is currently collecting. (see Appendix D for designated-use definitions). Although most tributaries to Curecanti still carry a Recreation 2 designation, the numeric standard is based on a Recreation 1 standard of 126 colony forming units of bacteria per 100mls. The Environmental Protection Agency has not accepted the State's rationale for this designation and the issue will most likely be resolved during the next rulemaking in 2006.

The park monitors core parameters, nutrients, trace elements, major ions, *E. coli*, macroinvertebrates, chlorophyll, and turbidity. Within these categories, the park must monitor *E. coli*, unionized ammonia, nitrate-nitrite, Cd, Cu, Pb, Mn, Se, Ag, and Zn since these are required under the Colorado anti-degradation review. These parameters are also used as a "hit list" by the state for rulemaking. Curecanti is the only park in the network that currently measures chlorophyll, a useful tool to measure eutrophication levels in reservoirs. The park will continue to monitor this attribute, as well as macroinvertebrates, since they have historical data and excellent reference sites. As mentioned earlier, the park would like to monitor volatile organic compounds, but realizes the expense associated with this parameter.

During the network workshop, a question arose regarding the susceptibility of BLCA/CURE waters to the effects of acidic deposition due to low buffering capacity of the waters, and atmospheric deposition of metals such as mercury. The USGS noted they had an atmospheric deposition network in the Rocky Mountains and throughout the west in cooperation with the NPS and other agencies. The USGS will work with the park and the NCPN to discuss data sources and issues regarding atmospheric deposition.

Table 30. Water quality vital signs for Curecanti National Recreation Area.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source				
	Gunnison River	Cimarron River	Major Tributaries	Lake Fork of the Gunnison	Reservoirs
Core Field Parameters	C-USGS	C-NPS	C- NPS	C- NPS	C- NPS
Stream flow	C-USGS	C- NPS	C- NPS	C- NPS	
Nutrients	C-USGS	C- NPS	C- NPS	C- NPS	C- NPS
Trace Elements	C-USGS	C- NPS	C- NPS	C- NPS	C- NPS
Major Ions	C-USGS	C- NPS	C- NPS	C- NPS	C- NPS
Microorganisms	C-USGS	C- NPS	C- NPS	C- NPS	C- NPS
Macroinvertebrates	C-USGS	C- NPS	C- NPS	C- NPS	
Chlorophyll		C- NPS	C- NPS	C- NPS	C- NPS
Carbon					
Organics (Pesticides) + VOC					
Turbidity		C- NPS	C- NPS	C- NPS	C- NPS
Priority	H	H	H	H	H
Schedule	7 samples/yr	7 samples/yr	7 samples/yr	7 samples/yr	7 samples/yr
Logistics	A	A	A	A	A

R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration.
Priority: H = High, M = Medium, L = Low
Logistics: A = Easy Access, D = Difficult Access

Dinosaur National Monument

Dinosaur National Monument spans two states, Colorado and Utah, and encompasses two significant water bodies, the Green and Yampa rivers. From the park's perspective, the Yampa is impaired, and the Green is threatened. Water depletions occur in both rivers, and non-native fish species and the exotic New Zealand mud snail are found in the Green River. Flaming Gorge Dam on the Green River has altered flows which lead to changes in vegetation composition and geomorphic processes. Numerous upland water sources including tributaries, springs and seeps, flow into or towards the Green and Yampa rivers, and are impacted by livestock use (11 allotments) and social trails along the river corridors. Upstream municipal wastewater plants amplify inputs of nutrients from livestock. Water quantity and quality issues may arise related to possible oil, gas, and coal bed methane exploration in the future.

Preliminary assessment by NCPN staff of the water quality data compiled in the database developed by the USGS reveals total phosphorus exceeding the Utah guidelines of 0.05 mg/L. However, these exceedences may coincide with high suspended solids levels in the river. This relationship needs to be examined for the monument, as well as for other parks with documented high total phosphorus levels. Few data results for pathogens and selenium exceed state standards. Some parameters are captured by other monitoring programs such as the US Fish & Wildlife's efforts with temperature and pH at various sites on the Green and Yampa rivers (1987 – present, see www.rb.fws.gov/ riverdata/). Salinity has been monitored in the Yampa River in the past. Recent analysis of pH indicates that a previously reported upward trend in pH may be attributable to poor methods and instrumentation occurring through the mid-80s (Chafin 2002).

The monument does not have a current monitoring program. Dinosaur NM and the NCPN network would like to monitor the Green River at the Gates of Ladore, the Yampa River at Deer Lodge, Cub Creek and Jones Hole Creek, the site of a fish hatchery. The discharge from the hatchery is sampled as part of the National Pollutant Discharge Elimination System (NPDES) program before it enters Jones Creek, but the park would like to take in-stream samples as well. The Green River at Jensen is monitored by the State of Utah, and should be continued. The USGS monitors quarterly at Steamboat, Deerlodge Park and Maybell on the Yampa River. The state of Utah samples the Green River at Brown Park. The desirability and possibility of expanding this frequency to 8 or 12 times per year should be explored.

For the approximately 90 springs in the park, two water quality studies have been completed (Rice 1998, Foster et al. 2000). The park recommends future sampling at these upland sites, though this effort may be a part of the NCPN's spring and seep inventory. Jones and Cub creeks are assigned future monitoring needs since the cost to include these may be prohibitive. UDWQ stated that it would analyze samples from the Colorado portion of the river at a reduced cost, where all of the recommended sites are located. Table 31 provides the suite of parameters that would be monitored.

The appearance of the exotic New Zealand mud snail in the Green River below Flaming Gorge dam prompted park personnel to ensure that Mark Vinson's macroinvertebrate data (Utah State University Bug Lab) are in USGS-NCPN database, and also prompted the need for macroinvertebrate monitoring on the Green and Yampa rivers. Future monitoring of pesticides in the Yampa River is also warranted as a result of the agricultural practices upstream.

Table 31. Water quality vital signs for Dinosaur National Monument.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source					
	Yampa River at Deerlodge Park	Green River at Gates of Ladore	Green River at Jensen	Upland Water Resources (~identified with impacts)	Jones Hole Cr.	Cub Cr.
Core Field Parameters	C-USGS	R	C-UT	R	F	F
Stream flow	C-USGS	R	C-USGS	R	F	F
Nutrients	C-USGS	R	C-UT	R	F	F
Trace Elements	C-USGS	R	C-UT		F	F
Major Ions	C-USGS	R	C-UT		F	F
Microorganisms	C-USGS	R		R		
Macroinvertebrates	C-USGS	R	C-UT	R		
Chlorophyll						
Carbon						
Organics (Pesticides)	F					
Turbidity	C-USGS	R	C-UT	R		
Priority	H	H	H	L - Monitoring, H - INVENTORY	M	M
Schedule	4/yr (USGS) CONSIDER EXPANDING TO 8/YEAR	7/yr	12/yr			
Logistics	A	A	A	A	A	A

R = Recommended New Monitoring Site, C = Current Monitoring to Continue,
F = Sites for Future Consideration
Priority: H = High, M = Medium, L = Low
Logistics: A= Easy Access, D = Difficult Access

Fossil Butte National Monument

The landscape at Fossil Butte NM consists of several flat-topped ridges and mesas with their surrounding slopes at the transition from sagebrush to aspen woodlands. Water resources are relatively scarce and drain from the protected lands inside the park. Chicken Creek is the largest drainage system inside the park. Its small flow is confined in an incised channel, some portions of which appear to be stabilizing. The monument was grazed for over 100 years before removal of livestock in 1989. Dams impounding some small stockponds have been removed in recent years. A spring and seep zone occurs at the contact between the relatively coarse Green River

Formation and the fine-textured Wasatch Formation. The springs feed approximately 20 ponds dammed by beavers, which are currently (2002-2003) dry due to drought. The aquifers supplying these springs are shallow and perched, and respond within 2-3 years to changes in precipitation. Fossil Butte NM supports one of the few sagebrush systems in the region that has been ungrazed for a decade or more.

Issues facing water quality at the park are primarily the result of channel adjustments on Chicken Creek due to past grazing, impoundments and lowering of the channel downstream. It is recognized that the concerns are primarily for channel geomorphology and sediment transport, and that water chemistry is a peripheral issue. The springs along the Green River/Wasatch contact face minimal threats from wildland fire management or atmospheric deposition. There is also a concern over a potential demand to develop water and pipe it outside of the park to support livestock.

No water quality monitoring is currently conducted in or near the park.

Cundick Spring, East and West Small Pox Springs, and the Green River Formation Springs are of medium priority for monitoring core parameters, discharge, trace elements and major ions. A suitable frequency is 4 times per year. This effort could be coordinated with the overall network spring & seep inventory. Chicken Creek is also of medium priority for monitoring the same vital signs at a frequency of 4-times/year. The water quality assessment should be aligned with assessment of aquatic, wetland and geomorphic indicators. Monitoring of discharge and geomorphic features along Chicken Creek would be valuable, but are outside the scope of this water quality program.

Table 32. Water quality vital signs for Fossil Butte National Monument.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source	
	Cundick Sp., E. & W. Small Pox Springs, Springs in Green River Formation	Chicken Creek
Core Field Parameters	F	F
Stream flow	F	F
Nutrients		
Trace Elements	F	F
Major Ions	F	F
Microorganisms		
Macroinvertebrates		
Chlorophyll		
Carbon		
Organics (Pesticides)		

Table 32 continued.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source	
	Cundick Sp., E. & W. Small Pox Springs, Springs in Green River Formation	Chicken Creek
Turbidity		
Priority	Medium	Medium
Schedule	4/yr	4/yr
Logistics	Easy	Easy
R = Recommended New Monitoring Site, C = Current Monitoring Recommended to Continue, F = Sites for Future Consideration.		

Golden Spike National Historic Site

The only perennial water in Golden Spike NHS is Blue Creek, which crosses the eastern end of the park for a very short distance. There are water quality concerns in the creek due to agricultural and industrial uses upstream. Utah-DWQ monitors Blue Creek at a site ("Blue Creek below Thiokol") 200-300 yards from the park. This is considered sufficient monitoring for this unit, therefore, no additional NCPN monitoring is recommended.

Hovenweep National Monument

Little Ruin, Hackberry, Cutthroat, Goodman Point canyons, and Cahon Spring are significant water sources for the park. These are located in the upper ends of canyons at the contact point between the porous Dakota Sandstone that caps the mesa and the underlying and more impervious Morrison shales. Each of these water resources provide a number of functions including wildlife habitat, development of riparian and floodplain zones, and scenic and recreational opportunities. All are in a natural condition and unimpaired in relation to Clean Water Act standards.

Impacts to springs may come from visitors, trespass cattle, oil and gas development and spills. For example, the 1992 Chuska oil spill at the Cajon Unit of Hovenweep dumped approximately 100 barrels of oil into the arroyo of that unit.

As part of the SEUG monitoring effort, park personnel monitor water quality and quantity at Little Ruin, Hackberry and Cahon springs. These are monitored on a rotational basis, whereby three sites are monitored per year. Hovenweep will be monitored beginning July 2003. The selected sites are monitored for one year and then revisited after two years. The same suite of parameters that are measured at Arches and Canyonlands are measured at Hovenweep. The UDWQ and the state lab analyze the water samples. The park places a high priority in maintaining their present monitoring plan. Refer to Arches and Canyonlands for more detailed discussions.

Table 33. Water quality vital signs for Hovenweep National Monument.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source		
	Little Ruin	Hackberry	Cahon Spring
Core Field Parameters	C-UT	C-UT	C-UT
Stream flow	C-UT	C-UT	C-UT
Nutrients	C-UT	C-UT	C-UT
Trace Elements	C-UT	C-UT	C-UT
Major Ions	C-UT	C-UT	C-UT
Microorganisms	C-UT	C-UT	C-UT
Macroinvertebrates	C-UT	C-UT	C-UT
Chlorophyll			
Carbon			
Organics (Pesticides)			
Turbidity			
Priority	H	H	H
Schedule	rotation of 12 samples/yr at three sites, each site sampled 1yr-on, 2yr-off, macroinvertebrates monitored quarterly on similar rotation, microorganisms sampled monthly on similar rotation		
Logistics	A	A	A
R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration Priority: H = High, M = Medium, L = Low Logistics: A = Easy Access, D = Difficult Access			

Natural Bridge National Monument

Water sources of significance in Natural Bridges National Monument include various seeps and springs in Tuwa, White, Armstrong, and To-ko-chi canyons. All of these sources are significant with regards to wildlife habitat, threatened and endangered species, scenic and recreational opportunities, and development of the riparian zone. All are in a natural condition.

Threats to the water resources at these sites include recreational overuse, and grazing and development outside of park boundaries. Uncontrolled camping and off-road vehicles can increase sedimentation in creeks. Camping and hiking around springs can trample vegetation and disturb associated aquatic organisms. Oil and gas development outside of park boundaries may contribute to water quality impacts; these may include spills and increased salinity and metal contamination.

As part of the Southeast Utah Group monitoring effort, park personnel monitor water quality and quantity at Tuwa, White and Armstrong springs. These are monitored on a rotational basis, whereby three sites are monitored per year. The selected sites are monitored for one year and then revisited after two years. The same suite of parameters that are measured at Arches, Canyonlands, and Hovenweep are also measured at Natural Bridges. Macroinvertebrates are monitored quarterly, and microorganisms are sampled monthly and analyzed in-house. The UDWQ and the state lab analyze the water samples. The park places a high priority in maintaining their present monitoring plan. Refer to Arches and Canyonlands for more detailed discussions.

Table 34. Water quality vital signs for Natural Bridges National Monument.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source		
	Tuwa	White	Armstrong
Core Field Parameters	C-UT	C-UT	C-UT
Stream flow	C-UT	C-UT	C-UT
Nutrients	C-UT	C-UT	C-UT
Trace Elements	C-UT	C-UT	C-UT
Major Ions	C-UT	C-UT	C-UT
Microorganisms	C-UT	C-UT	C-UT
Macroinvertebrates	C-UT	C-UT	C-UT
Chlorophyll			
Carbon			
Organics (Pesticides)			
Turbidity			
Priority	H	H	H
Schedule	Rotation of 12 samples/yr at three sites, each site sampled 1yr-on, 2yr-off, macroinvertebrates monitored quarterly on a similar rotation, microorganisms sampled monthly on similar rotation		
Logistics	Accessible	Accessible	Accessible
R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration Priority: H = High, M = Medium, L = Low			

Pipe Spring National Monument

Because springs are the primary natural resource at Pipe Spring NM, a major management issue is flow. Until recently there were four discharge points within the monument, Main Spring, Spring Room Spring, Tunnel Spring and West Cabin Spring. Both Main Spring and Spring Room Spring (Fort Spring) ceased flowing in 1999. The park then stabilized the adit of Tunnel Spring and currently pipes water up to the historic house/fort to maintain the appearance of water flowing through the spring room to the ponds outside. Water is also piped off the monument to meet a 1933 order from the Secretary of the Interior dividing the water between the monument, the Kaibab Band of Paiute Indians and to a Livestock Users Association. The water is distributed as follows: 1/3 to NPS, 1/3 to the Kaibab Paiute tribe, and 1/3 to the livestock users association. Under a 1970's agreement the park uses the tribal portion in exchange for potable water from the NPS well.

Threats to water quality are few. There are two small communities up gradient of the park and low numbers of livestock on lands outside the monument. Water quality monitoring would be more useful as a tool to indicate the relationships between the different discharge points and the potential changes in groundwater flow paths, than in response to potential contamination.

The park currently monitors discharge at all springs.

It was recommended that Tunnel Spring and West Cabin Spring be monitored for core parameters, major ions, trace elements and discharge. Flow monitoring will continue.

Table 35. Water quality vital signs for Pipe Spring National Monument.

Vital Sign (See Table 22 for individual parameters in each group)	WATER SOURCE Tunnel Spring, West Cabin Spring
Core Field Parameters	R
Stream flow	C-NPS
Nutrients	
Trace Elements	R
Major Ions	R
Microorganisms	
Macroinvertebrates	
Chlorophyll	
Carbon	
Organics (Pesticides)	
Turbidity	
Priority	Medium
Schedule	Quarterly
Logistics	Easy
R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration	

Timpanogos Cave National Monument

The American Fork River flows through a portion of Timpanogos Cave NM, though the cave itself is located on a mountainside far above the river. The monument contains three major cave ponds and approximately 30 smaller pools, all fed by groundwater percolating through the fractured rock.

A fish-consumption advisory from the Utah Division of Environmental Quality and the Utah Department of Health has been issued for the North Fork of the American Fork River. Recreational fishing does occur in the park. The advisory is for high levels of arsenic from mining activity upstream. The US Forest Service monitors the American Fork River extensively, so an additional NPS effort would be of low priority. Monitoring by the NPS should be reevaluated if monitoring by the USFS and UDWQ are dinscontinued.

Table 36. Water quality vital signs for Timpanogos Cave National Monument.

Vital Sign (See Table 22 for individual parameters in each group)	Water Source		
	Cave Pools & Drips	Seeps and Springs on Trail	American Fork River
Core Field Parameters	R	R	F
Stream flow	R		F
Nutrients	R		F
Trace Elements	R		F
Major Ions	R		F
Microorganisms		R	
Macroinvertebrates			
Chlorophyll			
Carbon			
Organics (Pesticides)			
Turbidity			F
Other		CAFFEINE OR OTHER HUMAN WASTE TRACER	
Priority	High*	Moderate for special project	Low
Schedule	2/month + storm	?	12/year
Logistics	Moderate hike, 2-4 hours RT	Moderate hike, 1-2 hours RT	Easy year round

R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration

* Current park project for cave water quality in 2003-2004; results of this study will aid in determining a monitoring strategy

The greatest management concerns are the cave waters, with major ions and trace elements of most interest. A preliminary recommendation was made for the monitoring of cave pools and drips pending the results of a current, two year NPS-WRD study.

A pit privy is located on the trail up to cave. There is concern that a potential source of contamination occurs from the privy to the springs downstream. The monument can repair the privy system thereby alleviating the need to monitor springs, however, the group conceded that monitoring for human waste or caffeine, combined with the core parameters, would be desirable.

Zion National Park

Within the deep canyons of Zion NP the main drainages include the East Fork of the Virgin River and the North Fork of the Virgin River. Other important perennial tributaries include North, La Verkin, Deep, Kolob, and Pine Creeks. Discharge from groundwater at numerous springs and hanging gardens are also important because many are isolated from other perennial waters. Wet vertical rock surfaces at hanging gardens provide unique aquatic habitats.

The state of Utah is currently reviewing a 303d listing for total dissolved solids in North Creek, a tributary that arises in the west central part of the park. The source of the TDS is almost certainly natural discharge from springs in the park, so corrective action would not be desirable from the park's perspective. Either conducting a TMDL process that recognizes the natural source of the dissolved minerals, or establishing standards that are consistent with the natural water chemistry would be preferred.

The majority of the stream flow in Zion NP is from groundwater discharge associated with the contact between the Navajo sandstone and the Kayenta formation. High visitor use occurs in the North Fork of the Virgin River in the Narrows section where some 2000 visitors hike the canyon per day. Coal bed methane leases exist in North Fork drainage, but no development has occurred yet. A preliminary data review by the park hydrologist showed high bacteria (fecal-coliform) in the North Fork of the Virgin River. This was most likely attributable to upstream livestock use of irrigated pastures on riverbanks, improper disposal of human waste by park visitors, or contamination from wildlife.

Existing monitoring by Utah DEQ includes the North and East Forks of the Virgin River near their confluence two miles downstream of the park, North Creek at Virgin, 4 miles downstream of the park, and La Verkin Creek, a cooperative BLM site, five miles downstream of the park. Currently, the park has no monitoring program.

Monitoring of a representative sample of hanging gardens is considered a medium priority. This would consist of rotating among six sites with two sites sampled each year. Discharge appears to be relatively steady through the year so that a sampling frequency of two times per year is recommended. Vital signs to be monitored include core parameters, nutrients and major ions. Discharge measurements would be difficult at these features. A similar pattern of sampling at representative springs and tinajas is recommended for future consideration. Utah DWQ is willing to include a minimal number of springs or hanging gardens as cooperative sites even though rivers and reservoirs are their highest priorities. All these features should be included in the planned seep/spring/hanging garden inventory, with modifications to the water quality monitoring evaluated as part of the analysis.

The highest priority sites for monitoring are (1) the North Fork of the Virgin River at the Temple of Sinawava, (2) at the road crossing upstream of the park on the North Fork of the Virgin River, (3) La Verkin Creek within the park, and (4) North Creek within the park. The North and East Forks of the Virgin River would be monitored for core parameters, nutrients, trace elements, major ions, macroinvertebrates, total dissolved solids, suspended solids and turbidity. This would be done cooperatively with the Utah DWQ. Additionally, the North Fork would be monitored for microorganisms. It is presumed that state monitoring downstream of the park on the North and East Forks of the Virgin River, North Creek and La Verkin Creek would continue.

Deep and Kolob Creeks are low priorities for monitoring due to their remote location and difficult access. Pine Creek is considered a low priority due to its minimal flow.

Table 37. Water quality vital signs for Zion National Park.

VITAL SIGN (See Table 22 for individual parameters in each group)	WATER SOURCE								
	N. Fork of Virgin R., at Temple of Sinawava	N. Fork of Virgin R., at N. Fork Bridge, upstream of park	E. Fork of Virgin R. Downstream of park	La Verkin Creek	North Creek, in Park	Springs/ Tinajas	Hanging Gardens	Deep Creek & Kolob Creek	Pine Creek
Core Field Parameters	R	R	C-UT	F	R	F	R	F	F
Stream flow	C-USGS	R	C-USGS	F	R	F		F	F
Nutrients	R	R	C-UT	F	R	F	R	F	
Trace Elements	R	R	C-UT	F	R			F	F
Major Ions	R	R	C-UT	F	R	F	R	F	F
Microorganisms	R	R		F	R				F
Macroinvertebrates	R		C-UT		R			F	F
Chlorophyll									
Carbon									
Organics (Pesticides)									
Turbidity	R	R	C-UT	F					
Other - sewage indicators						R	R		
Priority	H-chem H-invert. M-bact.	H-chem H-invert. M-bact.	H-chem H-invert. M-bact.	H-chem H-invert. M-bact.	H-chem- L- bact.	M	M	L	L
Schedule	12/yr.-	Monthly May-Oct	6/yr	12/yr	12/yr	2 sites, 2/yr Rotating	2 sites, 2/yr Rotating	?	?
Logistics	Easy	Accessible when dry	Easy, 30 min. hike	Difficult, 3 hour hike roundtrip	1 hour roundtrip hike, very hot in summer	Varies. Springs in narrows, difficult.	Easy, 10 min. hike	Very difficult, 4-8 hour hike, summer only	Easy, 5 min. hike
R = Recommended New Monitoring Site, C = Current Monitoring to Continue, F = Sites for Future Consideration Priority: H=High, M=Medium, L=Low									

XI. LITERATURE CITED

Alford, R. A., and S. J. Richards. 1999. Global amphibian declines: A problem in applied ecology. *Annual Review of Ecology and Systematics* 30: 133-165.

Allan, J. D. 1995. *Stream ecology: Structure and function of running waters*. Chapman & Hall, London. 388 pp.

Allen, C. D., and D. D. Breshears. 1998. Drought-induced shift of a forest-woodland ecotone: rapid landscape response to climate variation. *Proceedings of the National Academy of Science USA* 95: 14839-14842.

Allen, C. D., M. Savage, D. A. Falk, K. F. Suckling, T. Schulke, T. W. Swetnam, P. B. Stacey, P. Morgan, M. Hoffman, and J. T. Klingel. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: A broad perspective. *Ecological Applications* 12: 1418-1433.

Aronson, J., and E. Le Floc'h. 1996. Vital landscape attributes – missing tools for restoration ecology. *Restoration Ecology* 4: 377-387.

Asner, G. P., T. R. Seastedt, and A. R. Townsend. 1997. The decoupling of terrestrial carbon and nitrogen cycles. *BioScience* 47: 226-234.

Baron, J. S., N. L. Poff, P. L. Angermeier, C. N. Dahm, P. H. Gleick, N. G. Hairston, Jr., R. B. Jackson, C. A. Johnston, B. D. Richter, and A. D. Steinman. 2002. Meeting ecological and societal needs for freshwater. *Ecological Applications* 12: 1247-1260.

Belnap, J. 1998. Environmental auditing: Choosing indicators of natural resource condition: A case study in Arches National Park, Utah, USA. *Environmental Management* 22: 635-642.

Belnap, J. 2003. The world at your feet: desert biological soil crusts. *Frontiers in Ecology and Environment* 1: 181-189.

Belnap, J., and O. L. Lange, eds. 2001. *Biological soil crusts: Structure, function, and management*. Springer-Verlag, Berlin. 503 pp.

Bunn, S. E., and A. H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30: 492-507.

Butler, D. 2001. Unpublished table of water quality at springs in park. USGS Multiple Station Analyses.

Butler, D. L. and K.J. Lieb. 2002. *Characterization of Selenium in the Lower Gunnison River Basin, Colorado, 1988 – 2000*. U.S. Geological Survey, Water Resources Investigations Report 02-4151, Denver, Colorado.

Chafin, D.T. 2002. *Evaluation of trends in pH in the Yampa River, Northwestern Colorado, 1950-2000*. U.S. Geological Survey. Water-Resources Investigations Report 02-4038.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. *The American Naturalist* 148: 1016-1037.

Chapin, F. S., III, B. H. Walker, R. J. Hobbs, D. U. Hooper, J. H. Lawton, O. E. Sala, and D. Tilman. 1997. Biotic control over the functioning of ecosystems. *Science* 277: 500-504.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. M. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. *Ecological Applications* 6: 665-691.

Cole, D. N. 1990. Trampling disturbance and recovery of cryptogamic soil crusts in Grand Canyon National Park. *Great Basin Naturalist* 50: 321-325.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in western North America. *Wildlife Biology* 3/4: 123-128.

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. *Wildlife Society Bulletin* 28: 967-985.

Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2000. Ecological principles and guidelines for managing the use of land. *Ecological Applications* 10: 639-670.

Dale, V. H., and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* 1: 3-10.

Daszak, P., L. Berger, A. A. Cunningham, A. D. Hyatt, D. E. Green, and R. Speare. 1999. Emerging infectious diseases and amphibian population declines. *Emerging Infectious Diseases* 5: 735-748.

Daszak, P., A. A. Cunningham, and A. D. Hyatt. 2000. Emerging infectious diseases of wildlife – Threats to biodiversity and human health. *Science* 287: 443-449.

Davis, G. E. 1997. General ecological monitoring program design, implementation, and applications: a case study from Channel Islands National Park, California in J. K. Reaser and F. Dallmeier, eds. *Measuring and monitoring biodiversity for conservation science and adaptive management*. Smithsonian Institution, Washington, D.C.

Davis, J. C., G. W. Minshall, C. T. Robinson, P. Landres. 2001. *Monitoring wilderness stream ecosystems*. General Technical Report RMRS-GTR-70. Rocky Mountain Research Station, Fort Collins, CO.

Díaz, S., and M. Cabido. 2001. Vive la différence: plant functional diversity matters to ecosystem processes. *Trends in Ecology & Evolution* 16: 646-655.

Environmental Protection Agency (EPA). 2003. EPA Water Quality Monitoring Internet Site available at www.epa.gov/owow/monitoring/elements/elements.html#6.

Evenden, A., M. Miller, M. Beer, E. Nance, S. Daw, A. Wight, M. Estenson, and L. Cudlip. 2002. *Northern Colorado Plateau Vital Signs Network and Prototype Cluster, Plan for Natural Resources Monitoring: Phase I Report, October 1, 2002*. [Two volumes]. National Park Service, Northern Colorado Plateau Network, Moab, UT. 138 pp. plus appendices.

Fenn, M. E., R. A. Haeuber, G. S. Tonnesen, J. S. Baron, S. Grossman-Clarke, D. Hope, D. A. Jaffe, S. Copeland, L. Geiser, H. M. Rueth, and J. O. Sickman. 2003a. Nitrogen emissions, deposition, and monitoring in the western United States. *BioScience* 53: 391-403.

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, D. W. Johnson, and P. Neitlich. 2003b. Ecological effects of nitrogen deposition in the western United States. *BioScience* 53: 404-420.

Forman, R. T. T. 1995. *Land mosaics: The ecology of landscapes and regions*. Cambridge University Press, Cambridge. 632 pp.

Foster, M. J. Stednick, W. Rice. 2000. *Inventory and characterization of upland water resources in Dinosaur National Monument*. Colorado State University, Watershed Science Program. Fort Collins, CO. 80 pp.

Galloway, J. N., J. D. Aber, J. W. Erisman, S. P. Seitzinger, R. W. Howarth, E. B. Cowling, and B. J. Cosby. 2003. The nitrogen cascade. *BioScience* 53: 341-356.

H. John Heinz III Center for Science, Economics, and the Environment. 2002. *The state of the nation's ecosystems: Measuring the lands, waters, and living resources of the United States*. Cambridge University Press, New York. 270 pp.

Goodwin, C. N., C. P. Hawkins, and J. L. Kershner. 1997. Riparian restoration in the western United States: Overview and perspective. *Restoration Ecology* 5: 4-14.

Harwell, M. A., V. Myers, T. Young, A. Bartuska, N. Gassman, J. H. Gentile, C. C. Harwell, S. Appelbaum, J. Barko, B. Causey, C. Johnson, A. McLean, R. Smola, P. Templet, and S. Tosini. 1999. A framework for an ecosystem integrity report card. *BioSicence* 49: 543-556.

Herrick, J. E., W. G. Whitford, A. G. DeSoyza, and J. W. Van Zee. 1995. Soil and vegetation indicators for assessment of rangeland ecological condition. Pages 157-166 in C. Aguirre-Bravo, ed. *North American workshop on monitoring for ecological assessment of terrestrial and aquatic ecosystems. 1995, September 18-22; Monticello, Texcoco, México. Gen. Tech. Rep. RM-GTR-284*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO.

Herrick, J. E., J. R. Brown, A. J. Tugel, P. L. Shaver, and K. M. Havstad. 2002. Application of soil quality to monitoring and management: paradigms from rangeland ecology. *Agronomy Journal* 94: 3-11.

Hobbs, R. J., and S. E. Humphries. 1995. An integrated approach to the ecology and management of plant invasions. *Conservation Biology* 9: 761-770.

Janzen, D. H. 1983. No park is an island: Increase in interference from outside as park size decreases. *Oikos* 41: 402-410.

Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. *Oikos* 69: 373-386.

Karr, J. R. 1996. Ecological integrity and ecological health are not the same. Pages 97-109 in P. C. Schultz, ed. *Engineering within ecological constraints*. National Academy Press, Washington, D.C.

Karr, J. R. 2000. Health, integrity, and biological assessment: The importance of measuring whole things. Pages 209-226 in D. Pimentel, L. Westra, and R. F. Noss, eds. *Ecological integrity: Integrating environment, conservation, and health*. Island Press, Washington, D.C.

Karr, J. R., and E. Chu. 1999. *Restoring life in running waters: Better biological monitoring*. Island Press, Washington, D.C. 206 pp.

Keane, R. E., K. C. Ryan, T. T. Veblen, C. D. Allen, J. Logan, and B. Hawkes. 2002. *Cascading effects of fire exclusion in Rocky Mountain ecosystems: A literature review. Gen. Tech. Rep. RMRS-GTR-91*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. 24 pp.

Kunkle, S., W. S. Johnson, M. Flora. 1987. *Monitoring stream water for land-use impacts: a training manual for Natural Resource Management Specialists*. Water Resources Division, National Park Service, Fort Collins, CO.

Kurtz, J. C., L. E. Jackson, and W. S. Fisher. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. *Ecological Indicators* 1: 49-60.

Linstone, H. A., and M. Turoff, eds. 1975. *The Delphi method: Techniques and applications*. Addison-Wesley, Reading, MA. 620 pp. (See http://www.is.njit.edu/pubs/delphibook/.)

Logan, J. A., J. Régnière, and J. A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment* 1: 130-137.

Ludwig, J. A., N. Hindley, and G. Barnett. 2003. Indicators for monitoring minesite rehabilitation: trends on waste-rock dumps, northern Australia. *Ecological Indicators* 3: 143-153.

MacDonald, L. H. 1991. *Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska*. EPA-910/9-91-001. Environmental Protection Agency, Seattle, WA.

Malm, W. C. 1999. *Introduction to visibility*. Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins. 68 pp.

Maniero, T. 2001. *Air quality monitoring considerations for the Northern Colorado Plateau Network*. NPS Air Resources Division, Denver. 6 pp. plus appendices.

Meyerson, L. A., and J. K. Reaser. 2003. Bioinvasions, bioterrorism, and biosecurity. *Frontiers in Ecology and Environment* 1: 307-314.

Naiman, R. J., S. E. Bunn, C. Nilsson, G. E. Petts, G. Pinay, and L. C. Thompson. 2002. Legitimizing fluvial ecosystems as users of water: an overview. *Environmental Management* 30: 455-467.

National Park Service. 1994. *Southeast Utah Group water quality monitoring plan*. Moab, UT. 17 pp.

National Park Service. 2001. Management policies, 2001. Department of Interior, National Park Service, Washington, D.C. 137 pp. (http://data2.itc.nps.gov/npspolicy/index.cfm.)

National Park Service Water Resources Division (NPS-WRD). 2001. *Handbook for monitoring vital signs in National Parks, water quality draft guidance parts A, B, C, D and E*. National Park Service, Natural Resource Program Center, available at http://science.nature.nps.gov/im/monitor/handbook.htm.

Noon, B. R. 2003. Conceptual issues in monitoring ecological systems. Pages 27-71 in D. E. Busch and J. C. Trexler, eds. *Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives*. Island Press, Washington, D.C.

Noss, R. 1990. Indicators for monitoring biodiversity. *Conservation Biology* 4: 355-364.

Noss, R. F., E. T. LaRoe, III, and J. M. Scott. 1995. *Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological Report 28.* National Biological Service, Washington, D.C.

Oliver, I. 2002a. An expert panel-based approach to the assessment of vegetation condition within the context of biodiversity conservation: Stage 1: the identification of condition indicators. *Ecological Indicators* 2: 223-237.

Oliver, I. 2002b. Introduction to an expert panel based approach for the assessment of vegetation condition within the context of biodiversity conservation. *Ecological Management & Restoration* 3: 227-229.

O'Shea, T. J., and M. A. Bogan, eds. 2000. *Interim report of the workshop on monitoring trends in U.S. bat populations: Problems and prospects*. U.S. Geological Survey, Midcontinent Ecological Science Center, Fort Collins, CO. 124 pp.

O'Shea, T. J., M. A. Bogan, and L. E. Ellison. 2003. Monitoring trends in bat populations of the United States and territories: Status of the science and recommendations for the future. *Wildlife Society Bulletin* 31: 16-29.

Parrish, J. R., F. Howe, and F. Norvell, eds. 2002. *Utah Partners in Flight avian conservation strategy, version 2.0. UDWR Publication No. 02-27*. Utah Partners in Flight Program, Utah Division of Wildlife Resources, Salt Lake City. 302 pp.

Prichard, D., J. Anderson, C. Correll, J. Fogg, K. Gebhardt, R. Krapf, S. Leonard, B. Mitchell, J. Staats. 1998. *Riparian area management : A user guide to assessing proper functioning condition and the supporting science for lotic areas. Interagency technical reference 1737-15.* U.S. Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. 126 pp.

Prichard, D., F. Berg, W. Hagenbuck, R. Krapf, R. Leinard, S. Leonard, M. Manning, C. Noble, and J. Staats. 1999. *Riparian area management : A user guide to assessing proper functioning condition and the supporting science for lentic areas. Interagency technical reference 1737-16*. U.S. Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. 109 pp.

Pyke, D. A., J. E. Herrick, P. L. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. *Journal of Range Management* 55: 584-597.

Rice, W. J. 1998. *Water chemistry variation between lithologies in Dinosaur National Monument, Colorado*. Masters Thesis. Colorado State University, Fort Collins, CO.

Romme, W. H., K. D. Heil, J. M. Porter, and R. Fleming. 1993. *Plant communities of Capitol Reef National Park, Utah. Technical report NPS/NAUCARE/NRTR-93/02*. U.S. Department of Interior, National Park Service, Cooperative Park Studies Unit, Northern Arizona University, Flagstaff.

Sala, O. E., F. S. Chapin, III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L. F. Huenneke, R. B. Jackson, A. Kinzig, R. Leemans, D. M. Lodge, H. A. Mooney, M. Oesterheld, N. L. Poff, M. T. Sykes, B. H. Walker, M. Walker, and D. H. Wall. 2000. Global biodiversity scenarios for the year 2100. *Science* 287: 1770-1774.

Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: A review. *Conservation Biology* 5: 18-32.

Shakarjian, M. J., and J. A. Stanford. 1998. *Effects of trampling by hikers on zoobenthos of the North Fork of the Virgin River, Zion National Park, Utah*. Flathead Lake Biological Station, Polson, Montana. 16 pp.

Sisk, T. D., and N. M. Haddad. 2002. Incorporating the effects of habitat edges into landscape models: Effective area models for cross-boundary management. Pages 208-240 in J. Liu and W. W. Taylor, eds. *Integrating landscape ecology into natural resource management*. Cambridge University Press, Cambridge.

Smith, T., H.H. Shugart, and F.I. Woodward, eds. 1997. *Plant functional types*. Cambridge University Press, Cambridge. 369 pp.

Sousa, W. P. 1984. The role of disturbance in natural communities. *Annual Review of Ecology and Systematics* 15: 353-391.

Spence, J. R., and N. R. Henderson. 1993. Tinaja and hanging garden vegetation of Capitol Reef National Park, southern Utah, U.S.A. *Journal of Arid Environments* 24: 21-36.

Stein, S. J. 1988. Fire history of the Paunsaugunt Plateau in southern Utah. *Great Basin Naturalist* 48: 58-63.

Stein, B. A. 2002. *States of the Union: ranking America's biodiversity*. NatureServe, Arlington, Virginia. 25 pp. (http://www.natureserve.org/publications/biodiversity/summary.htm)

Stromberg, J. C. 2001. Restoration of riparian vegetation in the south-western United States: importance of flow regimes and fluvial dynamism. *Journal of Arid Environments* 49: 17-34.

Swarthout, E. C. H., and R. J. Steidl. 2001. Flush responses of Mexican spotted owls to recreationists. *Journal of Wildlife Management* 65: 312-317.

Swetnam, T. W., and J. L. Betancourt. 1990. Fire-Southern Oscillation relations in the southwestern United States. *Science* 249: 1017-1020.

Swetnam, T. W., and J. L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. *Journal of Climate* 11: 3128-3147.

Tegler, B., and M. A. Johnson. 1999. *Selecting core variables for tracking ecosystem change at EMAN sites*. Final report to Environment Canada Ecological Monitoring and Assessment Network (EMAN), Guelph, Ontario. Geomatics International Inc., Burlington, Ontario. 28 pp. (http://www.eman-rese.ca/eman/reports/publications/2000_eman_core_variables/)

Tongway, D. J., and N. Hindley. 2000. Assessing and monitoring desertification with soil indicators. Pages 89-98 in O. Arnalds and S. Archer, eds. *Rangeland desertification*. Kluwer, Dordrecht.

Turner, M. G., R. H. Gardner, and R. V. O'Neill. 2001. *Landscape ecology in theory and practice: Pattern and process*. Springer-Verlag, New York. 401 pp.

Vitousek, P. M. 1990. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. *Oikos* 57: 7-13.

Vitousek, P. M. 1994. Beyond global warming: ecology and global change. *Ecology* 75: 1861-1876.

Vitousek, P. M., H. A. Mooney, J. Lubchenko, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. *Science* 277: 494-499.

Welsh, S. L. 1978. Endangered and threatened plants of Utah: a reevaluation. *Great Basin Naturalist* 38: 1-18.

Welsh, S. L. 1979. Endangered and threatened plants of Utah: a case study. *Great Basin Naturalist Memoirs* 3: 69-80.

Welsh, S. L. 1989. On the distribution of Utah's hanging gardens. *The Great Basin Naturalist* 49: 1-30.

Welsh, S. L., and C. A. Toft. 1981. Biotic communities of hanging gardens in southeastern Utah. *National Geographic Society Research Reports* 13: 663-681.

Welsh, S. L., N. D. Atwood, S. Goodrich, and L. C. Higgins, eds. 1993. *A Utah flora. Second edition.* Brigham Young University, Provo, Utah. 986 pp.

Whisenant, S. G. 1999. *Repairing damaged wildlands: a process-oriented, landscape-scale approach*. Cambridge University Press, Cambridge. 312 pp.

White, P. S., and S. T. A. Pickett. 1985. Natural disturbance and patch dynamics: An introduction. Pages 3-13 in S. T. A. Pickett and P. S. White, eds. *The ecology of natural disturbance and patch dynamics*. Academic Press, San Diego.

Whitford, W. G. 1998. Validation of indicators. Pages 205-209 in D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, eds. *Ecosystem health*. Blackwell Science, Malden, MA.

Whitford, W. G. 2002. *Ecology of desert systems*. Academic Press, San Diego. 343 pp.

Wiens, J. A., B. Van Horne, and B. R. Noon. 2002. Integrating landscape structure and scale into natural resource management. Pages 23-67 in J. Liu and W. W. Taylor, eds. *Integrating landscape ecology into natural resource management*. Cambridge University Press, Cambridge.

XII. APPENDICES

Appendix A. Vital-Sign Evaluation and Selection Process

Prepared by:

Mark Miller, USGS-BRD
Ed Krumpe, University of Idaho
Troy Hall, University of Idaho

8 August 2003

Contents

Figures

Tables (Note: Due to their length, tables in **bold print** are presented at end of Appendix A.)

Introduction

This appendix summarizes the process used by the Northern Colorado Plateau Network (NCPN) to identify, evaluate, and select potential vital signs for monitoring. This process involved an internet-based Delphi survey, a vital-sign evaluation excercise (hereafter referred to as the "pre-workshop survey"), a vital-signs evaluation workshop, park visits and scoping, and information synthesis.

In addition to on-going literature review, all phases of this process were informed by scoping activities associated with the Phase I report (Evenden et al. 2002). The NCPN monitoring-needs database, developed on the basis of substantial input provided by park staff (see p. 17 and Appendix H of Phase I report), was used throughout the vital-signs identification process to ensure that previous park input was fully represented. Similarly, the synthesis of park management and monitoring issues presented in Appendix O of the Phase I report was a key information source that informed the vital-signs process. The report from the geoindicators workshop held in Moab during June 2002 (Appendix H, Phase II report) was another important element of Phase I scoping that was used to inform the vital-signs identification process.

Delphi Survey – Overview

The NCPN contracted with the University of Idaho to conduct an electronic, internet-based Delphi survey to obtain input from experts regarding the design of vital-signs monitoring in the 16 NPS units of the NCPN. The Delphi technique "...may be characterized as a method for structuring a group communication process so that that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" (Linstone and Turoff 1975:3). The Delphi method has been used elsewhere as an approach for obtaining input on the design of resource monitoring programs (e.g., Davis 1997; Oliver 2002a,b).

In cooperation with the University of Idaho, the NCPN conducted two rounds of internet-based Delphi surveys in which participants were asked to provide input to the identification of NCPN vital signs. The first round began by introducing goals of the program, explaining key concepts, and briefly describing the parks, their resources, and perceived threats. The first survey introduced a general, conceptual framework that has been adopted by the NCPN for considering monitoring needs (the Jenny-Chapin model; see Phase I report). Following the presentation of this background information, input from the participants was solicited regarding measurable ecosystem attributes to be considered as potential indicators for monitoring the health of terrestrial, riparian, wetland and aquatic ecosystems managed by NCPN parks. In addition, near the end of the survey input was solicited regarding measurable attributes and potential indicators for monitoring the condition of other natural resource values including paleontological resources, night skies, and soundscapes.

The objective of the first round was the generation of ideas – analogous to an electronic "brain-storming session" (Oliver 2002a). Participants were told that the estimated time commitment for completing the first-round survey was from 30 minutes to 1 hour, depending on the scope of their expertise and comments.

In the second round of the electronic survey, participants were presented with summarized first-round results and they were asked to evaluate and prioritize potential indicators or suites of indicators on the basis of several criteria pertaining to conceptual relevance, feasibility of implementation, response variability, and interpretability and utility (e.g., Kurtz et al. 2001). They were told that estimated time commitment for completing the second-round survey would be 1-2 hours. They were also told that these surveys were just one means by which the NCPN was acquiring input for monitoring design. Other means included targeted discussions with individual subject-matter experts and resource-management professionals, workshops, and literature reviews. Finally, participants were told that they had been invited to participate in the surveys because of their expertise pertinent to long-term ecological monitoring in NCPN parks.

Administration of the Delphi Survey

On January 26, 2003, the first round of the Delphi survey was sent via email to 237 scientists and natural resource experts to provide input to the NCPN Vital Signs Monitoring Program. Within the email was an internet link (http://www.cnr.uidaho.edu/wilderness/NCPN/NCPNSurvey.htm) which recipients could "click" to open the survey in their web browser. The list of invited participants was developed by NCPN to include scientists and resource-management specialists with expertise in ecological monitoring and ecosystems represented in NCPN parks (Table A-1). (A list of invitees is available on request from the NCPN.)

Table A-1. Categories of expertise of 237 Delphi-survey recipients.

Categories of technical expertise	No. of recipients	Categories of technical expertise	No. of recipients
Arid-land ecology / monitoring	54	Hanging gardens	4
Forest ecology	18	Climate	3
Vertebrate ecology	19	Air quality	8
Invertebrate ecology	8	Paleontology	16
Riparian ecology	18	Miscellaneous	7
Landscape ecology / remote sensing	18	NCPN Science Panel	6
Aquatic ecology, water quality, and hydrology	40	NPS Park, network, regional staff	18

The survey was developed using Microsoft FrontPage web authoring software. This allowed a web page to be created in which people could enter their answers directly in input fields on the web page and then submit them when they were finished. Their data were instantaneously sent to the University of Idaho FrontPage computer server and appended to an Excel data base. The actual results of the survey were organized, labeled and submitted by the University of Idaho to the NCPN ecologist in the form of detailed spreadsheets.

The rapid speed of collecting information via an internet survey is only one reason the electronic survey format was chosen. The survey also presented a wide variety of background information about the vital signs monitoring program and many considerations specific to the NCPN. Background information presented to participants included definitions of key terms and concepts, an overview of anthropogenic threats to NCPN resources, general monitoring questions of the NCPN, and the general conceptual model adopted by the NCPN for purposes of framing the monitoring program (the Jenny-Chapin model presented in the Phase I report). The majority of this background material was presented via links that would open separate browser windows. Thus participants already familiar with the NCPN program could bypass this information and proceed directly to the input tables. (This background material is accessible via the internet link provided above or upon request from the NCPN.)

Organization of the First-Round Delphi Survey

The first survey solicited input on five tables that pertained to major categories of ecosystems: (1) arid-semiarid shrubland, grassland, and pinyon-juniper woodland ecosystems, (2) montane shrubland, woodland, and forest ecosystems, (3) riparian and wetland ecosystems, (4) aquatic ecosystems, and (5) landscape-level processes. In each table, three columns were provided in which respondents were asked to identify:

1. The most important ecosystem processes that contribute to these desired ecosystem functions,
2. Measurable environmental attributes that provide insights regarding the functional status of these processes and their capacities for resistance and resilience, and
3. Comments explaining their answers.

Each table also provided the opportunity to identify additional ecosystem functions that could be considered in the monitoring program. Figure A-1 is an example showing the ecosystem function and process input tables with sample answers entered.

In the actual survey, respondents could type in answers to any or all of the boxes in the input table. They could also provide answers in any or all of the five ecosystem input tables, depending upon their level of knowledge and expertise.

Arid-Semiarid Shrubland, Grassland, and Pinyon-Juniper Woodland Ecosystems			
Desired ecosystem function	**Contributing ecosystem process**	**Associated measurable attributes (potential indicators)**	**Comments/rationale for nominating this attribute**
Conservation of soil & water resources and conditions (includes soil quality and water quality)	(Write your recommendations below.) Infiltration of water into soil	Example: Infiltration capacity	Example: Infiltration capacity is a dynamic measure that is impacted by management.
Conservation of characteristic biotic functional groups and native biodiversity	Seed production of native perennial grasses	Ratio of flowering shoots to vegetative shoots	Provides info about reproductive status of taxa that reproduce by seed
Conservation of natural disturbance regimes	Fuel accumulation in fire- adapted ecosystems	Cover, volume, &/or spatial distribution of fuel types	Provides info about likelihood & potential characteristics of fire in ecosystem
Conservation of regional atmospheric resources and conditions (includes climate and air quality)	Circulation of clean air	Spatial & seasonal variations in ozone concentrations	Provides info about air quality status
Other function			

Figure A-1. Sample input table from the first round of the Delphi Survey.

Response to First-Round Delphi Survey

Overall, 64 scientists and experts submitted completed internet surveys in the first round of the Delphi survey. This was considered an acceptable response for several reasons. First, in a Delphi survey it is common practice to send the survey to a large number of people who may have either relevant experience or expertise in a particular scientific field or who may have worked or conducted scientific studies in a particular park (i.e., one of the 16 parks in the NCPN). The survey asked people who had specific or relevant experience to participate. Many recipients responded that they believed that they did not have the level of expertise or particular knowledge in the NCPN parks that they felt was needed to complete the survey. Others responded that it had been quite a few years since they had conducted studies in these parks. Still others indicated that they could not meet our deadline for responding to the survey. This is acceptable and expected in a Delphi survey because the purpose of the survey is to collect detailed and informed responses from a wide range of people with specific relevant expertise (not to collect representative information from a general population). Furthermore, the response rate was limited by the relatively short deadline to which they were asked to respond. A number of people sent email responses explaining that because of other work assignments or responsibilities they could not respond by the deadline, and some requested to be given the opportunity to participate in the second round.

Survey recipients were asked to limit their response to only those questions within the topic or category of their expertise. The results show that most of the scientists who responded primarily limited their responses to only one or two categories for which they had expertise.

Another way to judge the adequacy of response is to examine the range of expertise represented by the respondents. Table A-2 shows that the 64 respondents reported that they had technical expertise in more than 17 different fields, with most listing more than one type of expertise. Arid-land ecology and ecology of invasive exotic species were the two fields identified most frequently.

Table A-2. Fields of technical expertise reported by respondents to the first Delphi survey.

Fields of Technical Expertise	N	Fields of Technical Expertise	N
Arid-land ecology	25	Ecology of invasive exotic species	20
Forest ecology	7	Landscape ecology	15
Riparian ecology	16	Population ecology (vertebrates)	11
Aquatic ecology	15	Population ecology (plants)	6
Air quality	3	Remote sensing	4
Climate	7	Resource management	14
Botany	12	Wildlife biology	11
Entomology	7	Monitoring theory	12
Soils / soil ecology	13	Other	18
		TOTAL RESPONDENTS*	64

*Respondents could check more than one field of expertise.

Respondents also were asked to indicate their professional position or status in one or more of six categories. These data are presented in Table A-3. About two thirds (62%) were academic scientists or federal government scientists. A much smaller proportion consisted of federal or state resource managers (13.9%) or state government scientists (5.1%). In summary, some 64 scientists with expertise in 35 different fields and from 7 categories of professional employment responded. Therefore, the first round of the Delphi survey can be judged to be quite successful.

Table A-3. Professional status of respondents to the first Delphi survey.

Professional Status	Percent	N
Academic scientist/researcher	30.4	24
Federal government scientist	31.6	25
State government scientist	5.1	4
Park or network staff (NPS NCPN)	6.3	5
Federal resource manager	11.4	9

Table A-3. continued.

Professional Status	Percent	N
State resource manager	2.5	2
Other	12.7	10
Total	100	79

As indicated above, actual results of the survey were organized, labeled and submitted by the University of Idaho to the NCPN ecologist in the form of detailed spreadsheets. (Raw survey results are available upon request from the NCPN.) Survey results were synthesized and summarized by the NCPN ecologist, and these synthesized results formed the basis of the second Delphi survey.

Organization of the Second-Round Delphi Survey

On March 4, 2003, the same set of 237 scientists and resource-management specialists were invited to participate in the second round of the NCPN Delphi survey. In the second-round survey (http://www.cnr.uidaho.edu/wilderness/NCPN/NCPN2ndSurvey.htm), recipients were presented with a categorized set of 312 environmental attributes and measures for consideration as candidate vital signs. The master list of candidate vital signs was synthesized from scientific literature and input provided during the first-round Delphi survey. Table A-4 presents the framework used to organize candidate vital signs in the second survey. (See Table A-5 at the end of this appendix for a full list of attributes and measures.)

Table A-4. Monitoring themes and associated categories of candidate vital signs considered in the second Delphi survey.

MONITORING THEME	VITAL SIGNS CATEGORY (n = number of candidate vital signs)	EXPLANATION
Ecosystem structure & function	Climate (15)	Abiotic & biotic indicators of climatic/ meteorological conditions.
	Air quality (17)	Abiotic & biotic indicators of air quality.
	Upland soil & water resources (41)	Abiotic & biotic indicators of upland (hill slope) hydrologic function, soil quality, soil-site stability, nutrient cycling.
	Upland disturbance regimes (14)	Abiotic & biotic indicators associated with the occurrence, likelihood, or management of fire and insect-related disturbances.
	Upland & riparian communities (38)	Biotic integrity; composition of vascular & nonvascular plant, vertebrate, and invertebrate communities; exotic plants & animals; effects of herbivory.
	Aquatic, riparian & wetland hydrologic/ geomorphic regimes (29)	Abiotic & biotic indicators of hydrologic / geomorphic regimes; hydrologic function; water quantity.
	Water quality (27)	Abiotic & biotic indicators of water quality.

Table A-4 continued.

MONITORING THEME	VITAL SIGNS CATEGORY (n = number of candidate vital signs)	EXPLANATION
	Aquatic communities (19)	Biotic integrity; composition of aquatic vertebrate & macroinvertebrate communities; exotic plants & animals.
	Landscape-level patterns (16)	System dimensions, connectivity, fragmentation, land-use & land-cover patterns.
Species/populations of concern	Species/populations of concern (40)	Threatened, endangered, rare, or endemic species; species otherwise of concern / interest.
Other natural resource values	Other natural resource values (14)	Paleontology, wilderness experience, solitude, dark night sky, natural soundscape, river-running hazards & campsites.
Stressors	Stressors (42)	Candidate vital signs for active monitoring of stressors impacting park natural resources, if not already included in other categories.

Participants were asked to review the subset of environmental attributes that fell within the scope of their professional expertise and to evaluate them as potential vital signs on the basis of four general evaluation criteria derived from NPS Inventory and Monitoring Program guidance and scientific literature[1]:

1. Management Significance & Utility. Vital signs must provide information that is meaningful and useful to park managers. The following statements describe vital-sign characteristics pertinent to this criterion:

   - Relevant to management issues and concerns;
   - Provides information useful for management decisions;
   - Sensitive to particular stressors affecting park resources, OR vital sign itself is a stressor or driver of resource change and variability;
   - Predicts changes in resource conditions that can be averted by management actions;
   - Produces results that are easily communicated and clearly understood and accepted by scientists, policy makers, managers, and the public;
   - Produces results with recognizable implications for stewardship, regulation, and/or research;
   - If associated with species-level (or population-level) monitoring, vital sign is an attribute of a species that is legally protected, endemic, harvested, alien, or otherwise of special interest or concern;
   - Can be applied across a wide range of ecosystems and ecosystem conditions (i.e., is not restricted in application to a particular site or system).

2. Ecological Significance & Scientific Validity. Vital signs must be ecologically significant and clearly justified on the basis of peer-reviewed literature and a scientifically sound conceptual framework. The following statements describe vital-sign characteristics pertinent to this criterion:

[1] Key sources for evaluation criteria: Kurtz et al. (2001), Tegler and Johnson (1999), Dale and Beyeler (2001), Herrick et al. (1995, 2002), Noss (1990), Whitford (1998, 2002), Pyke et al. (2002).

- Relevant to the ecological function or valued natural resource it is intended to represent, OR vital sign itself is a stressor or driver of resource change and variability;
- Peer-reviewed literature exists to support relevance of the vital sign;
- For ecosystem-level monitoring, vital sign reflects functional status of one or more key ecosystem processes or the status of ecosystem properties that are clearly related to these ecosystem processes [Note: replace term *ecosystem* with *landscape* or *population*, as appropriate];
- For ecosystem-level monitoring, vital sign reflects the capacity of key ecosystem processes to resist or recover from change induced by natural disturbances and/or anthropogenic stressors [Note: replace term *ecosystem* with *landscape* or *population*, as appropriate];
- Signifies impending change in the ecological system (i.e., is anticipatory);

3. Feasibility & Cost of Implementation. Sampling, analysis, and interpretation of vital signs must be technically feasible and cost-effective. For purposes of vital-sign evaluation, a cost-effective vital sign is defined as one with a high benefit:cost ratio – i.e., information benefits are high relative to total costs. The following statements describe vital-sign characteristics pertinent to this criterion:

- Well-documented methods exist;
- If well-documented methods do not exist, development is technically feasible and cost-effective;
- Logistical requirements are feasibly met (includes training, travel and site accessibility, sampling time per measurement and for the number of required replicates, sample transport, sample processing and analysis, etc.)
- Full costs of implementation are low relative to benefits gained from information (includes costs associated with protocol development and pilot studies, long-term sampling, instrumentation, analysis, data management, etc.)
- If specialized knowledge and/or instrumentation is required for data acquisition or analysis, benefits gained are high relative to costs associated with specialized knowledge and instrumentation;
- Sampling does not significantly impact the site or protected organisms (i.e., is nondestructive);
- Sampling does not significantly affect subsequent measurements of the same parameter or simultaneous measurements of other parameters.

4. Signal:Noise Ratio (Response Variability). Vital signs must be characterized by patterns of variability that are well understood and possess a high signal:noise ratio. That is, variability attributable to anthropogenic stressors must be high relative to variability attributable to natural processes or measurement errors. The following statements describe vital-sign characteristics pertinent to this criterion:

- Vital sign has limited and documented sensitivity to natural variation;
- Measurement errors introduced by human observers and/or instruments during data collection, transport, analysis, and management can be controlled and estimated;
- Factors driving short-term temporal variability are understood (including natural drivers and anthropogenic stressors) and can be estimated and evaluated;
- Factors driving long-term temporal variability are understood (including natural drivers and anthropogenic stressors) and can be estimated and evaluated;
- Factors driving spatial variability in data are well understood and can be accounted for via stratification or other means;
- Vital sign is able to discriminate differences among sites along a known condition gradient, and locations in similar "condition" yield similar measurements;
- Responds to stress in a predictable, unambiguous manner;
- Provides continuous assessment over wide range of stress;

- Discriminatory ability meets data quality objectives, factoring in variability as well as precision and confidence levels desired by the program.

Participants in the survey evaluated candidate measures by assigning them evaluation scores on a scale of 1-5 for each of the four criteria (Table A-6). Figure A-2 illustrates a sample vital-sign evaluation input form from the second Delphi survey.

Table A-6. Evaluation criteria and choices of ratings for candidate vital signs considered in second Delphi survey.

Evaluation Criteria	**Choices of Ratings for Each Criterion**
Management Significance & Utility	5. EXTREME significance & utility 4. HIGH significance & utility 3. MODERATE significance & utility 2. SLIGHT significance & utility 1. NO significance & utility No Answer
Ecological Significance & Scientific Validity	5. EXTREME significance & validity 4. HIGH significance & validity 3. MODERATE significance & validity 2. SLIGHT significance & validity 1. NO significance & validity No Answer
Feasibility & Cost of Implementation	5. EXTREMELY feasible & cost effective 4. HIGHLY feasible & cost effective 3. MODERATELY feasible & cost effective 2. SLIGHTLY feasible & cost effective 1. NOT feasible & cost effective No Answer
Signal:Noise Ratio (Response Variability)	5. EXTREMELY HIGH signal: noise ratio 4. HIGH signal: noise ratio 3. MODERATE signal: noise ratio 2. LOW signal: noise ratio 1. UNACCEPTABLY LOW signal: noise ratio No Answer

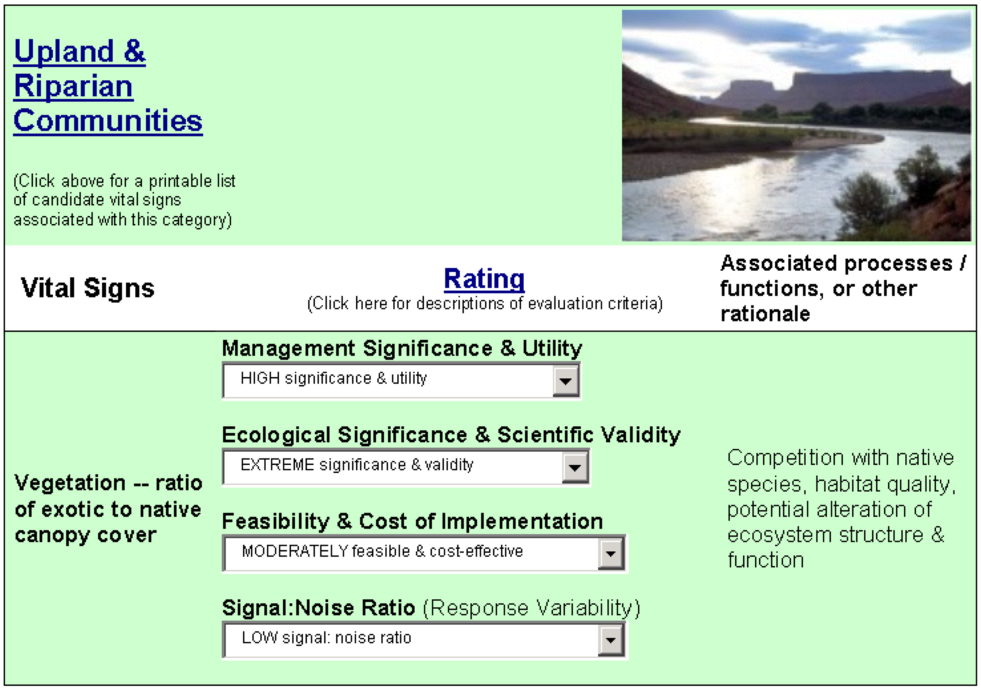


Figure A-2. Sample input form from the second Delphi survey.

General monitoring questions posed by NCPN parks provided the context for the evaluation of candidate vital signs (see pp. 62-63 of Phase I report, Evenden et al. 2002). Respondents could review these general monitoring questions by clicking on a link in the internet survey. Additional background material including program goals, definitions of key concepts (e.g., ecosystem health), and a description of the general ecosystem model adopted by the NCPN accompanied the first round of questioning and could also be seen by clicking on a link in the second survey.

Response to Second-Round Delphi Survey

Seventy-two scientists and experts submitted completed internet surveys in the second round of the Delphi survey. Given the complexity, wide distribution, and short time allowance for the survey, this was considered a good response. As in the first survey, recipients were asked to restrict their responses to those candidate vital signs within the scope of their professional expertise. Table A-7 shows that the respondents reported that they had technical expertise in more than 17 different fields. Arid-land ecology was again the most frequently cited field of expertise.

Table A-7. Fields of technical expertise reported by respondents to the second Delphi survey.

Fields of Technical Expertise	N	Fields of Technical Expertise	N
Arid-land ecology (including rangeland ecology)	29	Ecology of invasive exotic species (plants and/or animals)	15
Forest ecology	10	Landscape ecology	14
Riparian ecology (including fluvial geomorphology of arid-land streams & rivers)	20	Population ecology and monitoring of rare and/or sensitive vertebrates including avifauna, amphibians, mammals, and/or fish	10

Table A-7 continued.

Fields of Technical Expertise	N	Fields of Technical Expertise	N
Aquatic ecology (including water quality)	16	Population ecology and monitoring of rare and/or sensitive plants	11
Air quality	3	Remote Sensing	3
Climate	4	Resource Management	17
Botany	15	Wildlife Biology	6
Soils and soil ecology	14	Monitoring theory	12
Entomology	11	Other*	14
		TOTAL RESPONDENTS**	72

*Other fields of expertise listed by respondents included such things as paleontology, fire ecology, wetland restoration, chemistry, geology, statistics, and biogeochemistry.
**Respondents could check more than one field of expertise.

Finally, respondents were also asked to indicate their professional position or status in one or more of six categories. These data are presented in Table A-8. About two thirds (64%) were academic scientists or federal government scientists. A very small proportion consisted of state government scientists (3.8%) or federal or state resource managers (9%).

Table A-8. Professional status of respondents to second Delphi survey.

Professional Status	Percent	N
Academic scientist/researcher	29.5	23
Federal government scientist	34.6	27
State government scientist	3.8	3
Park or network staff (NPS NCPN)	12.8	10
Federal resource manager	7.7	6
State resource manager	1.3	1
Other	10.3	8
Total	100	78

Detailed data displaying the responses to all of the survey questions were compiled by the University of Idaho and submitted to the NCPN ecologist in the form of Excel spreadsheets. On the basis of evaluation scores assigned to candidate vital signs, the NCPN ecologist reviewed input from the second-round survey and used professional judgement to reduce the candidate set from 312 to 164 attributes or measures (see Appendix Table A-5). During the review process, it became apparent that survey participants commonly misinterpreted the concept of signal:noise ratio. Consequently, evaluation scores for this criterion were not incorporated in the overall scores used to rank and reduce the candidate set. (Raw survey results and evaluation scores for candidate vital signs are available upon request from the NCPN.)

Pre-Workshop Vital-Sign Evaluation Survey

In late March and early April 2003, a final round of vital-sign evaluation was conducted in preparation for the NCPN vital-sign workshop scheduled for 7-11 April 2003. The reduced set of 164 candidate vital signs was incorporated in a MS Access database designed to facilitate the evaluation of candidates on the basis of 13 relatively specific evaluation criteria (Table A-9).

These specific criteria were related to the general criteria applied during the second round of the Delphi survey and, like the general criteria, were derived from scientific literature and NPS Inventory and Monitoring Program guidance. The ultimate purpose of the evaluation exercise was to collect data that would aid the development of network-level vital-sign priorities during the subsequent workshop.

Organization of the Survey

Following examples and guidance provided by NPS Inventory and Monitoring Program staff, USGS staff in Moab designed the NCPN vital-sign evaluation database (1) to facilitate the rapid evaluation of 2132 combinations of 164 candidate vital signs and 13 evaluation criteria, and (2) to capture the data resulting from these evaluations. A key feature of the database was a user-friendly data entry screen that presented an array of contextual information (e.g., vital sign theme, category, and rationale for consideration) and automatically stepped participants through the evaluation process (Figure A-3). (The MS Access vital-sign evaluation database is available upon request from the NCPN.)

On March 24th, 2003, the pre-workshop vital-signs evaluation database was distributed with instructional materials to NCPN network and park staff, key USGS and academic cooperators, and NCPN science-panel members. Participants were asked to evaluate candidate measures by assigning them evaluation scores on a scale of 0-5 for each of the 13 criteria. They also were asked to restrict their evaluations to those candidate measures and criteria that were within their scope of professional knowledge. NCPN parks were asked to submit single consolidated responses for their parks. NCPN network staff, USGS and academic partners, and science-panel members all completed the survey from a network-wide perspective rather than on a park-specific basis.

Table A-9. Vital-sign evaluation criteria used by the NCPN during the pre-workshop evaluation exercise and during the April 2003 vital-signs workshop. Unless noted otherwise, for each candidate vital sign (environmental attribute or measure) participants were instructed to score all criteria from 0-5 where 0 indicated total disagreement with the stated criterion and 1-5 reflected differing degrees of agreement from weak (1) to very strong (5). If interpreted as simple yes-no statement, 0=no and 5=yes.

1. MANAGEMENT SIGNIFICANCE & UTILITY		**Explanatory Comments / Considerations**
1.1	Degree of legislative / policy mandate associated with vital sign.	**Scoring approach:**
		5. Required by Endangered Species Act, Clean Water Act, Clean Air Act (Class 1 airsheds), or park enabling legislation that mentions specific resource.
		4. Specifically covered by an Executive Order (e.g., invasive plants, wetlands) or by a specific Memorandum of Understanding signed by NPS (e.g., bird monitoring).
		3. Vital sign is associated with a resource or issue that is specifically covered by a GPRA goal or some type of federal or state law in addition to the Organic Act and other general legislative mandates and NPS Management Policies.
		2. Vital sign is associated with a resource that is specifically mentioned in park General Management Plan or Resource Management Plan (or similar document).
		1. Vital sign is not covered by any of the specific mandates listed above, but is associated with a resource or issue that is covered by the Organic Act, other general legislative mandates, and/or NPS Management Policies.
		0. Applicable, but none of the above.
		Not applicable: Vital signs associated with natural drivers of resource change and variability or anthropogenic stressors.
1.2	Vital sign is pertinent to one or more specific management concerns.	Overlaps with criterion 1.1, but criterion 1.2 should be scored to reflect degree of management concern independent of any specific mandate. Other considerations pertinent to this criterion: Vital sign should be responsive to one or more stressors affecting park resources. There should be an obvious, direct application of the data to a key management decision, or for evaluating the effectiveness of past management actions. If associated with species-level (or population-level) monitoring, vital sign should be an attribute of a species that is legally protected, endemic, harvested, endemic, alien, or otherwise of special interest or concern. Management concern may be attributable to the fact that the resource has high public appeal.
1.3	Vital sign reliably predicts adverse changes that can be averted by management actions.	For purposes of resource protection and management, a vital sign that predicts adverse changes before they occur (i.e., serves as early warning) is more useful than one that reflects adverse changes only after they have occurred. (Some vital signs may do both.) Likewise, a vital sign that predicts changes that can be averted by management actions is more useful than a vital sign that predicts changes that cannot be averted by management. Ideally, vital signs that indicate resource conditions should be responsive to management actions within a relatively short period of time.

Table A-9 continued.

	1. MANAGEMENT SIGNIFICANCE & UTILITY	**Explanatory Comments / Considerations**
1.4	Vital sign produces results (data & interpretations) that are easily communicated, easily understood, and accepted by scientists, policy makers, managers, and the general public, all of whom should recognize implications of vital signs results for protecting and managing the park's resources.	Vital signs that are easily communicated and understood may have greater management utility than those that are not.
	2. ECOLOGICAL SIGNIFICANCE & SCIENTIFIC VALIDITY	**Explanatory Comments / Considerations**
2.1	Vital sign reliably reflects the status of key ecosystem processes or properties. **OR** if vital sign represents a stressor or natural driver of ecosystem change, then the stressor / driver strongly affects functioning of one or more critical ecosystem processes / properties.	**NOTE:** Replace term *ecosystem* with *landscape, population, or other resource* as appropriate. Relationship between vital sign and associated process or property should be supported by peer-reviewed literature.
2.2	Vital sign reflects the capacity of critical ecosystem processes to resist or recover from change caused by natural disturbances and/or anthropogenic stressors.	**NOTE 1:** Replace term *ecosystem* with *landscape, population* or other *resource* as appropriate. **NOTE 2:** Vital signs that represent anthropogenic stressors or climate should be scored as **Not Applicable**.
2.3	Vital sign is anticipatory -- i.e., reflects an impending change in key components or functions of the ecosystem or other natural resource.	Similar to criterion 1.3, a vital sign that predicts or anticipates impending ecological changes is more useful than a vital sign that reflects ecological changes only after they have occurred.
	3. FEASIBILITY & COST OF IMPLEMENTATION	**Explanatory Comments / Considerations**
3.1	Vital sign can be cost-effectively measured.	Consider technical / logistical feasibility, availability of existing methods, and full costs of methods development and implementation (includes training, instrumentation, preparation time, travel & site accessibility, sampling time, sample transport, sample processing & analysis, long-term data management, etc.). Benefits (information value) gained from vital sign should be high relative to total costs incurred. The most cost-effective vital sign is that which indicates the most (in terms of overall resource condition) for the least cost.
3.2	Measurement of vital sign is nondestructive.	Measurement of vital sign should not impact site conditions or protected organisms. Measurement should not affect simultaneous measures of other vital signs or subsequent measures of the same vital sign.
	4. RESPONSE VARIABILITY	**Explanatory Comments / Considerations**
4.1	Measurement of vital sign can repeatedly and reliably sort human-caused changes from natural changes over a wide range of resource conditions.	**NOTE: Default answer for natural drivers (e.g., climate) and anthropogenic stressors is YES.** Other considerations: Measurement of vital sign should be repeatable by different observers and by same observer at a different time. Natural and human factors affecting spatial and temporal variability in the vital sign should be well-understood and reliably differentiated. Vital sign should respond to human factors in predictable, unambiguous manner and should be able to discriminate among sites along a known condition gradient. Vital sign should be capable of providing a continuous assessment over a wide range of stress.

Table A-9 continued.

5. EXISTING DATA & PROGRAMS		**Explanatory Comments / Considerations**
5.1	Vital sign has been inventoried or is already monitored **within** park (i.e., baseline data are available).	In general, more data are better (e.g., number of years and/or number of stations) -- but the *quality* of existing baseline data also should be considered in relation to this criterion.
5.2	Vital sign is monitored **outside** of park (e.g., by other agencies or regional/national monitoring programs).	In general, more data are better (e.g., number of years and/or number of stations) -- but the *quality* of existing outside data also should be considered in relation to this criterion.
5.3	Data associated with this vital sign are readily available, shared, and/or can be obtained from elsewhere at minimal expense to I&M program.	Some forms of monitoring may be accomplished by acquiring data from other existing sources rather than from new field measurements.
6. PROGRAM INTEGRATION		**Explanatory Comments / Considerations**
6.1	Integrative – the full **SUITE** of vital signs spans key environmental gradients (e.g., soils, elevation, terrestrial > riparian > aquatic), ecological hierarchy (landscapes, ecosystems, populations), spatial scales, and system characteristics / components (including structure, function, and composition).	Applies to full suite of candidate or selected vital signs rather than to individual vital signs.

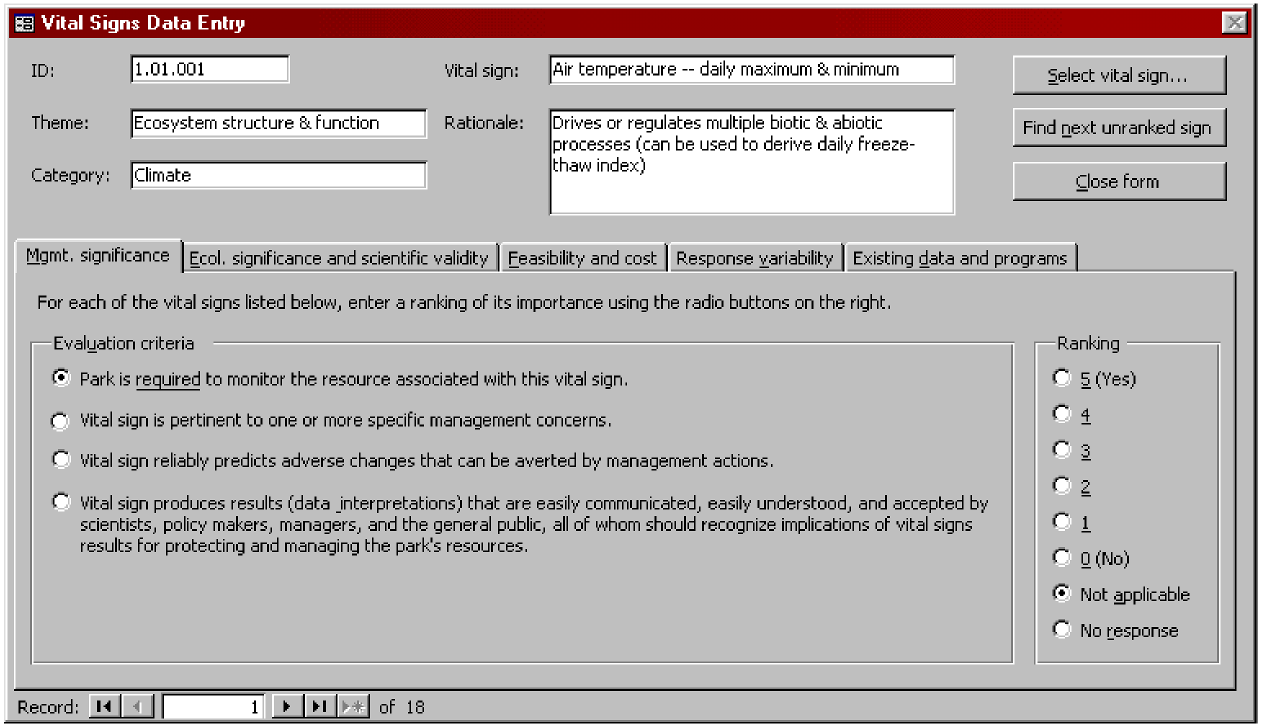


Figure A-3. Sample data-input screen from the vital-sign evaluation database used during the pre-workshop vital-sign evaluation survey.

Response to the Survey

Twenty-three parks or individuals participated in the pre-workshop vital-sign evaluation survey (Table A-10). An automated process was used to compile the data and calculate average evaluation scores for candidate attributes and measures. For purposes of calculating an overall total evaluation score for each candidate, each of the five criteria categories included in Table A-9 (excluding the sixth category) was given equal proportional weight (thus weights varied among individual criteria). On the basis of overall evaluation scores averaged across all survey participants, candidate attributes and measures were ranked *within categories* to form a preliminary prioritization of candidate attributes and measures. This ranked list of candidates was the starting point for vital-sign discussions held during the workshop. In preparation for the vital-sign workshop, survey participants were provided with matrices which summarized their individual (or park) evaluation scores as well as the overall evaluation scores averaged across all participants.

Table A-10. Participants in the NCPN pre-workshop vital-sign evaluation survey.

Affiliation	Participants
NCPN parks	Arches National Park
	Black Canyon of the Gunnison National Park
	Bryce Canyon National Park
	Canyonlands National Park
	Capitol Reef National Park
	Cedar Breaks National Monument (completed by Zion staff)
	Colorado National Monument
	Curecanti National Recreation Area
	Hovenweep National Monument
	Natural Bridges National Monument
	Pipe Spring National Monument (completed by Zion staff)
	Zion National Park
NCPN staff and cooperators	Angie Evenden
	Mark Miller
	Elizabeth Nance
	Sonya Daw
	Lynn Cudlip (Western State College, Gunnison, CO)
NCPN science panel members	Buck Sanford, University of Denver
	Tim Seastedt, University of Colorado
	Jack Schmidt, Utah State University
USGS cooperators	Jayne Belnap
	Tim Graham
	Mike Scott

Vital-Signs Workshop

On 7-9 April 2003, a 2 ½ – day NCPN vital-signs workshop was held in Moab. Purposes of the workshop were (1) to review results of the pre-workshop vital-sign evaluation exercise, and (2) to identify network-level vital-sign priorities on the basis of cross-network commonalities in evaluation results and previously identified program emphases. Participants included NPS staff from parks and the network (including managers and technical staff), USGS and academic cooperators, and NCPN science-panel members (Table A-11). Water quality vital signs, though included in the Delphi and pre-workshop surveys, were addressed separately during a subsequent two-day workshop on 10-11 April 2003 (see Appendix C).

Table A-11. Participants in the NCPN vital-signs workshop, 7-9 April 2003, Moab.

Name	Affiliation
Adams, Mike	Research Ecologist, USGS-BRD Corvallis OR
Alward, Rich	Ecologist, USGS-BRD Moab UT
Beer, Margaret	Data Manager, NCPN, Moab UT
Belnap, Jayne	Research Ecologist, USGS-BRD Moab UT
Bradybaugh, Jeff	Chief of Resources and Research, Zion National Park, Springdale UT
Cahill, Kelly	Biological Technician, Bryce Canyon National Park, Bryce Canyon UT
Clark, Tom	Chief of Resources, Capitol Reef National Park, Torrey UT
Cudlip, Lynn	Research Associate, Western State College, Gunnison CO
Daw, Sonya	Biologist, NPS NCPN / Southeast Utah Group, Moab UT
Evenden, Angela	Program Manager, NPS NCPN, Moab UT
Graham, Tim	Research Ecologist, USGS-BRD Moab UT
Hiebert, Ron	NPS Research Coordinator, Colorado Plateau Cooperative Ecosystem Studies Unit, Flagstaff AZ
Kim, Sharon	Wildlife Biologist, Zion National Park, Springdale UT
Kokaly, Ray	Geophysicist, USGS-GD Denver CO
Krumpe, Ed	Professor of Resource Recreation and Tourism, University of Idaho, Moscow ID
Kyte, Clayton	Biologist, Fossil Butte National Monument, Kemmerer WY
Louie, Denise	Botanist / Vegetation Program Manager, Zion National Park, Springdale UT
Miller, Mark	Ecologist, NPS NCPN, Moab UT
Nance, Elizabeth	Data Specialist and Biologist, NCPN, Moab UT
Naumann, Tamara	Botanist, Dinosaur National Monument, Dinosaur CO
Noon, Barry	Professor of Fishery and Wildlife Biology, Colorado State University, NCPN Science Panel Member, Fort Collins CO
Price, Dave	Natural Resource Specialist, Colorado National Monument, Fruita CO
Schelz, Charlie	Biologist, NPS Southeast Utah Group, Moab UT
Schmidt, Jack	Associate Professor, Department of Aquatic, Watershed, and Earth Resources, Utah State University, NCPN Science Panel Member, Logan UT
Scott, Mike	Research Ecologist, USGS-BRD, Fort Collins CO
Seastedt, Tim	Professor of Biology, University of Colorado-Boulder, NCPN Science Panel Member, Boulder CO
Sharrow, Dave	Hydrologist, Zion National Park, Kanab UT
Stahlnecker, Ken	Chief of Resource Stewardship and Science, Curecanti National Recreation Area and Black Canyon of the Gunnison National Park, Gunnison CO
Thomas, Lisa	Program Manager, NPS Southern Colorado Plateau Network, Flagstaff AZ
Truett, Joe	Senior Biologist, Turner Endangered Species Fund, NCPN Science Panel Member, Glenwood NM
Wakefield, Gery	GIS Manager, NPS Southeast Utah Group, Moab UT

Workshop Process and Outcomes

During the first half of the workshop, participants discussed average evaluation scores associated with particular measures and evaluation criteria (Table A-9). To facilitate the discussion, matrices summarizing overall (average) evaluation scores and individual evaluation scores (i.e., those scores submitted by individual participants in the pre-workshop survey) were digitally projected onto screens at the front of the workshop meeting room. Numerous evaluation scores were revised to reflect group decisions concerning the relative merits of various environmental attributes or measures in relation to the evaluation criteria. After the group reached a consensus regarding the evaluation scores assigned to all of the measures and attributes under consideration, relative weighting schemes were discussed. This discussion focused on whether the five criteria categories (Table A-9, excluding the sixth category) should receive equal or different weights in calculating total scores for each candidate, and whether individual criteria should be eliminated or emphasized. To develop a final overall ranking of candidate attributes and measures, the group decided to apply the following relative weights to criteria categories:

- Management Significance & Utility – 35%
- Ecological Significance & Scientific Validity – 35%
- Feasibility and Cost of Implementation – 20%
- Response Variability – 10%
- Existing Data and Programs – 0%

No weight was given to the Existing Data and Programs category because the group decided that candidate attributes or measures should not be "penalized" for not having been monitored in the past. Weights were applied to the consensus evaluation scores, and the resulting overall evaluation scores were used to produce a final ranking of candidate attributes and measures. Table A-12 (at the end of this Appendix) presents consensus evaluation scores accepted by the group and candidate vital signs ranked within categories on the basis of overall weighted evaluation scores. [Although existing monitoring data and programs did not contribute to overall vital-sign evaluation scores during the April workshop, these did play a significant role in the assignment of park-specific vital-sign priorities presented in the main body of the Phase II report.]

To aid group discussion and modification of vital-sign rankings derived from consensus evaluation scores (i.e., Table A-12), strips of paper with vital-sign descriptions and scores were posted on the wall of the workshop meeting room (Figure A-4). Workshop participants were organized into small workgroups and allowed 1-2 hours to review, rearrange, and annotate posted vital signs. After the workgroup discussions, all participants reconvened as a single group to discuss vital signs on a category-by-category basis. The objective of this discussion was to a agree upon network-level vital-sign priorities informed by evaluation results and previously identified program emphases.

Given budgetary constraints of the program, it was anticipated that the list of network-level vital-sign priorities would be considerably shorter than the full list of measures under consideration. Nevertheless, very few candidate attributes and measures were dropped from consideration during group discussion. Some candidate measures that previously had been trimmed from the list (e.g., following the second Delphi survey) were reconsidered and added back to the list. (Appendix Table A-4 indicates measures retained after workshop.) The outcome of the workshop was that the group validated nearly the full list of considered measures as a good set of potential vital signs. However, relative priorities remained ambiguous.

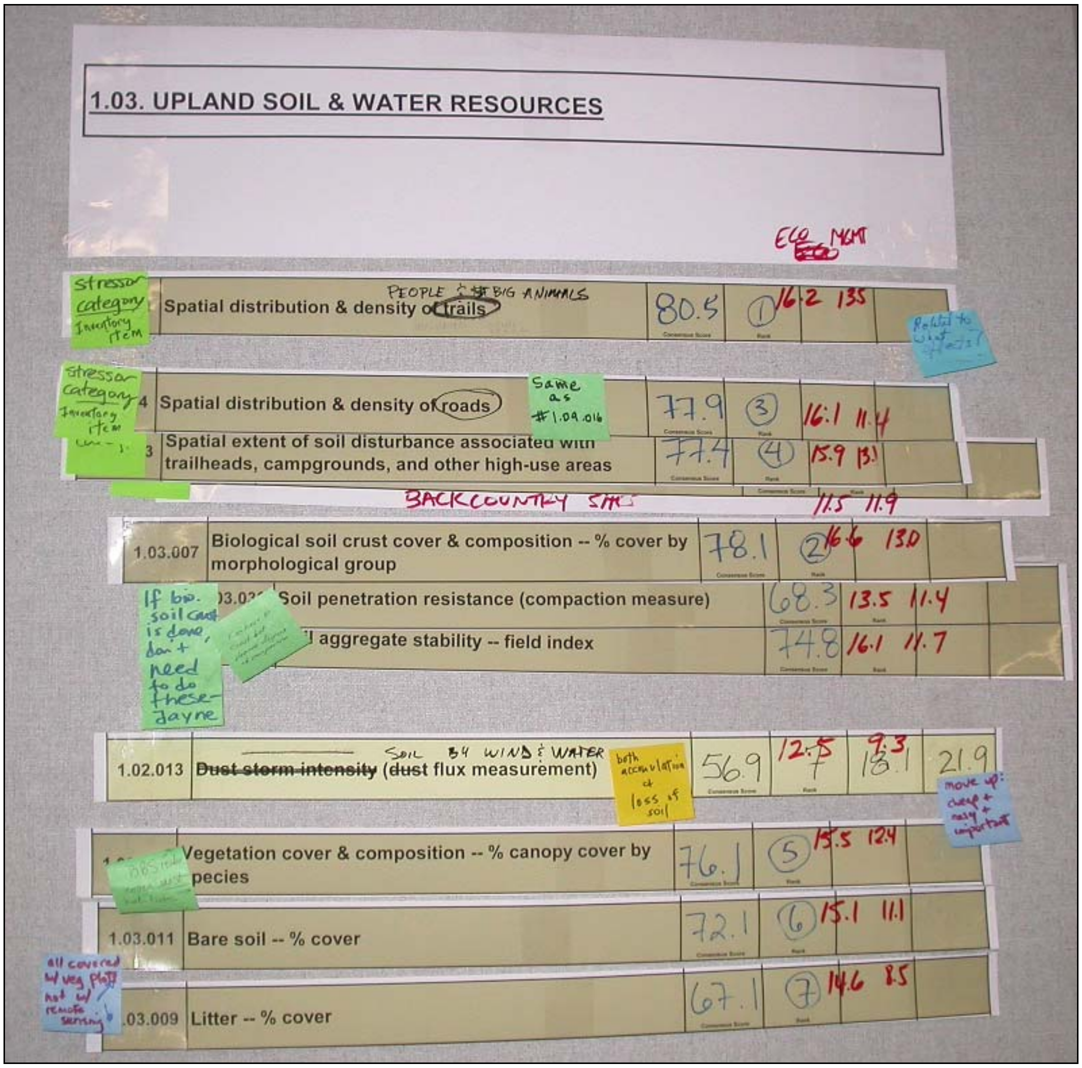


Figure A-4. Candidate vital signs posted on meeting-room wall and annotated by participants in April 2003 NCPN vital-sign workshop.

Workshop Challenges and Issues

It is important to acknowledge several issues associated with vital-sign selection that arose during the workshop. Many of these are interrelated and are also associated with other aspects of the vital-sign evaluation process. These issues are identified briefly below, though an in-depth assessment of them is beyond the scope of this document.

- *The workshop process itself* – Throughout the workshop, but particularly during the early stages, several alternative approaches to vital-sign evaluation were suggested by participants. Most of these were linked in some way to issues described below. All of the suggested approaches had merit, but the group decided to proceed with the process as planned because of time constraints.

- *Specificity versus generality in the vital-sign concept* – Beginning with the Delphi process, the NCPN approached vital signs at a relatively detailed level. For example, in the first round of the Delphi survey, the NCPN solicited input from a broad scientific community regarding specific *measures* of key ecosystem processes or components. Thus many candidate vital signs considered during the second round of the Delphi process, the pre-workshop evaluation exercise, and the workshop itself were specific measures of structural or functional attributes of ecosystems (see Table A-4). Many of the evaluation criteria found in scientific literature pertaining to ecological indicators are more appropriately applied to specific measures than to general ecosystem attributes (e.g., those criteria associated with response variability). This reinforced the detailed NCPN approach. Despite some advantages to the detailed approach, it greatly increased the complexity and overall magnitude of the vital-sign identification task. This was particularly evident during the workshop – when participants struggled to deal with the burden in an intense 2.5-day meeting. Subsequent to the workshop, NCPN staff synthesized workshop results and aggregated detailed vital signs to a more generalized level (see below).

- *Place and time specificity* – Related to the issue of vital-sign specificity, place-and-time specificity was an issue that repeatedly arose during the workshop. Usually this happened when comparing two or more measures that differed greatly in relative merit depending on the spatiotemporal context. Given the heterogeneity of management issues and biophysical environments among and within 16 NCPN units, it was impossible to deal with this level of detail in the workshop or preceding steps. Spatiotemporal specificity of monitoring questions and objectives will be a major focus during early stages of Phase III.

- *Cost considerations in relation to vital-sign evaluation and identification* – An on-going objective of the NCPN has been to frame a monitoring program that, in outline, identifies key park monitoring needs for purposes of maintaining and restoring the integrity of park ecosystems. NCPN from the outset has recognized that base funding associated with the vital-signs monitoring program will be insufficient to meet this comprehensive set of needs. Nevertheless, there is considerable value in scoping out a relatively comprehensive set of vital signs both for strategic purposes and for purposes of facilitating integrated whole-system thinking. This objective, as well as the associated NCPN vision that vital-signs monitoring ultimately will be accomplished through a variety of funding mechanisms and partnerships (and that some vital-signs may remain unfunded), was never made explicit during the workshop. Thus some workshop participants were frustrated by the fact that programmatic funding constraints played a relatively minor role in vital-sign evaluation discussions.

- *Vital signs as ecological indicators – or not?* – The official NPS definition of the vital-sign concept continues to evolve. Equating vital signs with the concept of *ecological indicators* (environmental attributes or measures that are particularly information-rich in the sense that they are somehow indicative of ecosystem integrity or condition), while at the same time recognizing that some vital-signs may be identified solely on the basis of human values, creates problems with communication and credibility among participants in the vital-sign identification process. [Of course this side-steps the notion that ecological integrity is itself a concept derived from human values.] Some participants in the NCPN workshop clearly differed in their perspectives on the proper scope of the vital-sign concept, and these differing perspectives contributed friction to an already-complex process.

- *The role and utility of ecological conceptual models* – The time and energy required from NCPN staff to manage the Delphi process and subsequent vital-sign evaluation exercises did not allow further development and refinement of ecological conceptual models presented in the Phase I report. Other than the Jenny-Chapin model adopted by the NCPN as a general model for ecosystem sustainability (Chapin et al. 1996; Evenden et al. 2002, Fig. 13, p. 78), conceptual models did not play an explicit role in the vital-sign evaluation process. However, because the Jenny-Chapin model was the basis for the organizational framework used throughout the vital-sign evaluation and selection process (Table A-4), it strongly shaped the types of generalized environmental attributes and measures that were considered and ultimately identified by NCPN as vital signs. It is clear that more-detailed conceptual models will be required to inform site-specific monitoring design, including determination of the most appropriate measures of vital signs in particular spatiotemporal contexts (see Appendix H, this Phase II report).

Post-Workshop Follow-Up and Synthesis

After the April 2003 workshop, the NCPN ecologist engaged in round of follow-up visits to parks. All NCPN parks were visited by network staff during May-June 2003 to identify park-specific monitoring needs and increase network familiarity with park resources and issues. Also during this period, network staff worked closely with the Southern Colorado Plateau Network (SCPN) in developing unified conceptual-modeling approaches (see Appendix H, this Phase II report); vital-signs frameworks; and inventory, assessment and monitoring protocols for springs, seeps, and hanging gardens.

As indicated above, an outcome of the workshop was the evident need to aggregate attributes and measures considered during the vital-sign evaluation and selection process with the intent of identifying vital signs at a more-generalized level of detail. Park visits, coordination with the SCPN, and a reconsideration of input received during various phases of the vital-signs evaluation process facilitated the reorganization of candidate attributes and measures retained after the April workshop. These relatively specific measures were synthesized and aggregated by the NCPN ecologist into a shorter list of vital-sign candidates that is broadly applicable across the NCPN (Table A-13). This list was subsequently reviewed and accepted by park staff, and it served as the foundation for the development by NCPN and park staff of park-specific vital-sign tables presented in the body of the Phase II report. Potential measures associated with these vital signs are presented in Appendix B.

Table A-13. Vital signs of broad applicability across the NCPN. List was derived from synthesis and aggregation of candidate measures retained following the April 2003 vital-signs workshop. See Appendix B for potential measures associated with individual vital signs.

Vital-Sign Category		VITAL SIGN
Ecosystem characteristics		
Climatic conditions		Precipitation patterns
		Air temperature patterns
		Wind patterns
Air quality		Atmospheric deposition
		Visibility
		Tropospheric ozone levels
Soil, water, and nutrient dynamics		Upland soil / site stability
		Upland hydrologic function
		Nutrient cycling
		Stream flow regime
		Stream / wetland hydrologic function
		Groundwater dynamics
Water quality		SEE WATER QUALITY TABLES
Disturbance regimes		Fire regimes
		Hillslope erosional processes
		Extreme climatic events
		Insect / disease outbreaks in forests and woodlands
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities (particular communities of interest may vary among parks in relation to values, threats, and probability/consequences of change.)
	At-risk species or communities	Status of at-risk species – amphibian populations
		Status of at-risk species – bat populations
		Status of at-risk species – Mexican spotted owl populations
		Status of at-risk species – peregrine falcon populations
		Status of at-risk species – other TES vertebrate populations (spp. vary by park)
		Status of at-risk species – TES plant populations (spp. vary by park)
		Status of at-risk communities – riparian-obligate birds
		Status of at-risk communities – sagebrush-obligate birds
		Status of at-risk communities – pinyon-juniper-obligate birds
		Status of at-risk communities – native fish communities
		Status of at-risk communities – native grassland / meadow plant communities
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities
	At-risk species or communities / Focal species or communities	Status of at-risk / focal communities – riparian / wetland plant communities
	Focal species or communities	Status of focal communities – biological soil crusts
		Status of focal communities – aquatic macroinvertebrates
		Status of focal communities – other aquatic communities (communities vary by park)
	Focal species or communities / Endemic species or unique communities	Status of focal / unique communities – spring, seep, & hanging-garden communities
	Endemic species or unique communities	Status of rare / endemic plant populations (spp. vary by park)
		Status of other unique communities (communities vary by park)
Landscape-level patterns		Land cover
		Land use
		Land condition
		Park insularization
		Landscape fragmentation and connectivity
Other vital-sign categories		
Stressors		Park use by visitors
		Invasive exotic plants
		Invasive, exotic, and/or feral animals
		Occurrence patterns of novel diseases / pathogens

Table A-13 continued.

Vital-Sign Category	VITAL SIGN
Other vital-sign categories	
Stressors	Permitted consumptive / extractive activities on park lands
	Park administration and operations
	Changes in stream hydrologic regimes due to surface-water diversions
	Changes in stream hydrologic regimes due to large reservoirs
	Changes in groundwater hydrologic regimes due to groundwater extraction
	Adjacent / upstream land-use activities
	Non-compliant uses on park lands
Other natural resource values	Status of paleontological resources
	Status of natural night skies
	Status of natural soundscapes

Literature Cited

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. *The American Naturalist* 148: 1016-1037.

Dale, V. H., and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* 1: 3-10.

Davis, G. E. 1997. General ecological monitoring program design, implementation, and applications: a case study from Channel Islands National Park, California in J. K. Reaser and F. Dallmeier, eds. *Measuring and monitoring biodiversity for conservation science and adaptive management*. Smithsonian Institution, Washington, D.C.

Evenden, A., M. Miller, M. Beer, E. Nance, S. Daw, A. Wight, M. Estenson, and L. Cudlip. 2002. *Northern Colorado Plateau Vital Signs Network and Prototype Cluster, Plan for Natural Resources Monitoring: Phase I Report, October 1, 2002*. [Two volumes]. National Park Service, Northern Colorado Plateau Network, Moab, UT. 138 pp. plus appendices.

Herrick, J. E., W. G. Whitford, A. G. DeSoyza, and J. W. Van Zee. 1995. Soil and vegetation indicators for assessment of rangeland ecological condition. Pages 157-166 in C. Aguirre-Bravo, ed. *North American workshop on monitoring for ecological assessment of terrestrial and aquatic ecosystems. 1995, September 18-22; Monticello, Texcoco, México. Gen. Tech. Rep. RM-GTR-284*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO.

Herrick, J. E., J. R. Brown, A. J. Tugel, P. L. Shaver, and K. M. Havstad. 2002. Application of soil quality to monitoring and management: paradigms from rangeland ecology. *Agronomy Journal* 94: 3-11.

Kurtz, J. C., L. E. Jackson, and W. S. Fisher. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. *Ecological Indicators* 1: 49-60.

Linstone, H. A., and M. Turoff, eds. 1975. *The Delphi method: Techniques and applications*. Addison-Wesley, Reading, MA. 620 pp. (See http://www.is.njit.edu/pubs/delphibook/)

Noss, R. 1990. Indicators for monitoring biodiversity. *Conservation Biology* 4: 355-364.

Oliver, I. 2002a. An expert panel-based approach to the assessment of vegetation condition within the context of biodiversity conservation: Stage 1: the identification of condition indicators. *Ecological Indicators* 2: 223-237.

Oliver, I. 2002b. Introduction to an expert panel based approach for the assessment of vegetation condition within the context of biodiversity conservation. *Ecological Management & Restoration* 3: 227-229.

Pyke, D. A., J. E. Herrick, P. L. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. *Journal of Range Management* 55: 584-597.

Tegler, B., and M. A. Johnson. 1999. *Selecting core variables for tracking ecosystem change at EMAN sites*. Final report to Environment Canada Ecological Monitoring and Assessment Network (EMAN), Guelph, Ontario. Geomatics International Inc., Burlington, Ontario. 28 pp. (http://www.eman-rese.ca/eman/reports/publications/2000_eman_core_variables/)

Whitford, W. G. 1998. Validation of indicators. Pages 205-209 in D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, eds. *Ecosystem health*. Blackwell Science, Malden, MA.

Whitford, W. G. 2002. *Ecology of desert systems*. Academic Press, San Diego. 343 pp.

Table A-5. Master list of environmental attributes and measures considered as potential vital signs during the second round of the Delphi survey, the pre-workshop vital-sign evaluation survey, and the April 2003 vital sign workshop. Attributes and measures retained after the April 2003 workshop were aggregated by NCPN staff to develop endpoint-based vital signs.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – CLIMATE					
1.01.001	Air temperature -- daily maximum & minimum	Drives or regulates multiple biotic & abiotic processes (can be used to derive daily freeze-thaw index)	X	X	X
1.01.002	Air temperature -- hourly average	Drives or regulates multiple biotic & abiotic processes	X		
1.01.003	Relative humidity -- hourly average	Drives or regulates multiple biotic & abiotic processes	X		
1.01.004	Precipitation -- amount per day	Drives or regulates multiple biotic & abiotic processes	X	X	X
1.01.005	Precipitation -- form (rain vs. snow)	Drives or regulates multiple biotic & abiotic processes	X	X	X
1.01.006	Precipitation events -- frequency, magnitude, and duration	Drives or regulates multiple biotic & abiotic processes, including erosion of soils and fossiliferous geologic strata	X	X	X
1.01.007	Soil temperature -- daily maximum & minimum	Drives or regulates multiple biotic & abiotic processes (can be used to derive daily freeze-thaw index)	X		
1.01.008	Soil temperature -- hourly average	Drives or regulates multiple biotic & abiotic processes	X		
1.01.009	Soil moisture -- hourly average	Drives or regulates multiple biotic & abiotic processes	X		
1.01.010	Wind velocity -- hourly average & peak gust	Drives or regulates multiple biotic & abiotic processes, including erosion of soils and fossiliferous geologic strata	X		
1.01.011	Wind direction -- hourly average	Directional component to resource redistribution	X		
1.01.012	Wind events -- frequency, magnitude, and duration	Drives or regulates multiple biotic & abiotic processes, including erosion of soils and fossiliferous geologic strata	X	X	X
1.01.013	UV radiation -- hourly average	Stressor affecting physiological processes	X		
1.01.014	Photosynthetically active radiation (PAR) -- hourly average	Required for photosynthetic activity	X		
1.01.015	Plant phenology (date of "green-up," flowering, or other life-history events)	Integrated indicator of climatic conditions	X	X	
Ecosystem Structure & Function – AIR QUALITY					
1.02.001	Nitrogen compounds -- atmospheric deposition	Nutrient enrichment, acidification	X	X	X
1.02.002	Sulfur compounds -- atmospheric deposition	Nutrient enrichment, acidification	X	X	X
1.02.003	Sulfur dioxide -- atmospheric concentration	Physiological stressor	X		
1.02.004	Major cations & anions -- atmospheric deposition	Mineral inputs	X	X	X
1.02.005	Air toxics (organics, pesticides, metals, radionucleides) -- atmospheric deposition	Contaminants	X		
1.02.006	Air toxics -- atmospheric concentrations	Contaminants	X		
1.02.007	Ozone -- atmospheric concentrations	Physiological stressor	X	X	X
1.02.008	Particulates -- atmospheric concentrations	Visibility impacts	X	X	X
1.02.009	Visibility -- visual range	Air-quality related resource value	X	X	X
1.02.010	Visibility -- light extinction	Air-quality related resource value	X	X	X
1.02.011	Visibility -- deciview	Air-quality related resource value	X	X	X

Table A-5 continued.

ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
Ecosystem Structure & Function – AIR QUALITY					
1.02.012	Dust storm frequency & duration	Soil redistribution, potential nutrient enrichment, visibility impairment	X	X	
1.02.013	Dust storm intensity (dust flux measurement)	Soil redistribution, potential nutrient enrichment, visibility impairment	X	X	
1.02.014	Ozone-sensitive plants -- foliar injury, physiological performance	Stress response	X	X	X
1.02.015	Lichens -- tissue chemistry	Bioaccumulation	X		
1.02.016	Lichens -- physiological performance	Stress response			
1.02.017	Surface water chemistry (pH, nutrient & toxin concentrations, acid neutralizing capacity)	Effects of atmospheric deposition		X	
1.02.018	Precipitation pH	Indicates acid inputs			
Ecosystem Structure & Function – UPLAND SOIL & WATER RESOURCES					
1.03.001	Spatial distribution & density of trails	Erosion susceptibility, soil biotic activity, nutrient cycling, soil water-holding capacity, watershed hydrologic function	X	X	X
1.03.002	Spatial distribution, abundance & extent of road-side pullouts	Erosion susceptibility, soil biotic activity, nutrient cycling, soil water-holding capacity, watershed hydrologic function	X		
1.03.003	Spatial extent of soil disturbance associated with trailheads, campgrounds, and other high-use areas	Erosion susceptibility, soil biotic activity, nutrient cycling, soil water-holding capacity, watershed hydrologic function	X	X	X
1.03.004	Spatial distribution & density of roads	Watershed hydrologic function, erosion susceptibility	X	X	X
1.03.005	Spatial extent and degree of deflation terrain	Aeolian soil movement & erosion	X		
1.03.006	Soil aggregate stability -- field index	Soil stability, soil biotic activity, infiltration capacity, soil organic matter content	X	X	X
1.03.007	Biological soil crust cover & composition -- % cover by morphological group	Soil stability, soil biotic activity, nutrient cycling	X	X	X
1.03.008	Biological soil crust biomass	Soil stability, soil biotic activity, nutrient cycling	X		
1.03.009	Litter -- % cover	Soil stability, organic matter inputs	X	X	X
1.03.010	Rock -- % cover	Soil stability	X		
1.03.011	Bare soil -- % cover	Erosion susceptibility	X	X	X
1.03.012	Downslope fetch-length of unvegetated patches	Erosion susceptibility	X		
1.03.013	Vegetation cover & composition -- % canopy cover by species	Rainfall interception, soil surface protection, wind obstruction, organic matter inputs	X	X	X
1.03.014	Vegetation cover & composition -- % basal cover by species	Overland flow obstruction, soil & water retention, infiltration capacity	X		
1.03.015	Vegetation structure -- canopy height	Wind obstruction	X		
1.03.016	Vegetation -- ratio of long-lived grasses to short-lived grasses	Resistance to drought & other disturbances, erosion susceptibility	X		
1.03.017	Vegetation -- seed production	Regeneration potential, indicates resilience to drought & other disturbances, erosion susceptibility	X		
1.03.018	Soil surface roughness	Overland flow obstruction, soil & water retention, infiltration capacity	X		

Table A-5 continued.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – UPLAND SOIL & WATER RESOURCES					
1.03.019	Soil organic matter content	Soil biotic activity, nutrient cycling, soil stability, infiltration capacity	X		
1.03.020	Soil color	Soil organic matter content, soil biotic activity, degree of biological soil crust development	X		
1.03.021	Soil CO_2 flux after rewetting	Soil biotic activity	X		
1.03.022	Root biomass	Soil biotic activity, soil-holding capacity	X		
1.03.023	Decomposition rate	Soil biotic activity, nutrient cycling	X		
1.03.024	Total soil carbon & nitrogen pools	Soil biotic activity, nutrient cycling	X		
1.03.025	Soil respiration rate	Soil biotic activity, nutrient cycling	X		
1.03.026	Soil nitrogen mineralization rate	Soil biotic activity, nutrient cycling	X		
1.03.027	Soil nitrogen isotope ratios	Soil biotic activity, nutrient cycling	X		
1.03.028	Soil food web composition, structure, & dynamics	Soil biotic activity, nutrient cycling	X		
1.03.029	Soil bulk density (compaction measure)	Infiltration capacity, soil water-holding capacity, soil biotic activity, nutrient cycling	X		
1.03.030	Soil penetration resistance (compaction measure)	Infiltration capacity, soil water-holding capacity, soil biotic activity, nutrient cycling	X	X	X
1.03.031	Infiltration rate	Water retention, erosion susceptibility, soil water-holding capacity, soil biotic activity, nutrient cycling	X		
1.03.032	Spatial variability in soil-quality attributes (e.g., sub-canopy values vs. interspace values)	Indicates change in spatial distribution of soil resources	X		
1.03.033	Changes in soil-surface height from benchmark	Soil erosion & deposition	X		X
1.03.034	Distribution & abundance of natural sediment traps (e.g., woody debris)	Watershed capacity for soil & water retention	X		
1.03.035	Soil movement / accumulation due to fluvial processes (e.g., deposition behind silt fences or natural sediment traps)	Watershed hydrologic function, runoff & erosion	X		X
1.03.036	Arroyo channel cross sections	Watershed hydrologic function, runoff & erosion	X		
1.03.037	Flow frequency of ephemeral streams in relation to precipitation events in well-defined watersheds	Watershed hydrologic function, runoff & erosion	X		
1.03.038	Discharge of small streams in relation to precipitation events in well-defined watersheds	Watershed hydrologic function, runoff & erosion	X		
1.03.039	Sediment loads in small streams in relation to precipitation events in well-defined watersheds	Watershed hydrologic function, runoff & erosion	X		
1.03.040	Nutrient concentrations in small streams in relation to precipitation events in well-defined watersheds	Watershed hydrologic function, runoff & erosion	X		
1.03.041	Slope movement	Mass wasting, watershed stability	X		
1.03.042	Number, distribution, and condition / spatial extent of backcountry campsites	Erosion susceptibility, soil biotic activity, nutrient cycling, soil water-holding capacity, watershed hydrologic function.		X	X
1.03.043	Soil movement / accumulation due to aeolian processes -- dust traps				X

Table A-5 continued.

ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
Ecosystem Structure & Function – UPLAND DISTURBANCE REGIMES					
1.04.001	Fine surface fuels -- distribution, cover and spatial continuity	Fuel accumulation, indicates potential for carrying surface fire	X	X	X
1.04.002	Fine surface fuels -- ratio of exotic cover to native cover	Relative contribution of exotic plants to fine-fuel accumulation	X	X	X
1.04.003	Ladder fuels -- distribution & abundance	Fuel accumulation, indicates potential for canopy fires	X		
1.04.004	Fuel types -- distribution & abundance	Fuel accumulation, indicates potential occurrence & characteristics of fire	X		
1.04.005	Fire occurrence on park lands -- frequency, spatial patterning, intensity, and timing	Directly reflects fire regime, drives change in multiple ecosystem properties & functions, affects landscape-level patch structure & diversity	X	X	X
1.04.006	Fire occurrence on adjacent lands -- frequency, spatial patterning, intensity, and timing	Potential impacts on within-park fire regimes	X	X	
1.04.007	Proportions of park lands in different "fire regime current-condition classes"	Depicts degree of departure from historical fire regime within park	X	X	X
1.04.008	Proportions of adjacent lands in different "fire regime current-condition classes"	Potential impacts on within-park fire regimes	X		
1.04.009	Spatial distribution of fire regime current-condition classes on park lands (a map)	Facilitates assessment & communication of fire-regime conditions	X	X	X
1.04.010	Spatial distribution of fire regime current-condition classes on adjacent lands (a map)	Facilitates assessment & communication of external fire-regime conditions that may impact park resources	X	X	
1.04.011	Fire management / suppression activities on park lands	Direct management impacts on within-park fire regimes	X	X	X
1.04.012	Fire management / suppression activities on adjacent lands	Potential impacts on within-park fire regimes	X		
1.04.013	Vegetation -- distribution & abundance of diseased or insect-infested trees in woodland / forest ecosystems	Insect disturbance, fire potential	X		X
1.04.014	Vegetation -- ratio of insect-infected to uninfected trees in woodland / forest ecosystems	Insect disturbance, fire potential	X		X
1.04.015	Vegetation -- distribution & abundance of drought-killed trees in woodland / forest ecosystems	Drought disturbance, fire potential			X
Ecosystem Structure & Function – UPLAND & RIPARIAN COMMUNITIES					
1.05.001	Soil food web composition, structure, & dynamics	Biodiversity component, multiple ecosystem functions	X		
1.05.002	Biological soil crust cover & composition -- % cover by morphological group	Biodiversity component, invasion susceptibility (mediates plant establishment), habitat structure / stability, multiple ecosystem functions	X	X	X
1.05.003	Vegetation cover & composition -- % canopy cover by species	Biodiversity component, habitat structure, multiple ecosystem functions	X	X	X
1.05.004	Vegetation composition -- frequency by species	Biodiversity component, habitat structure, other ecosystem functions	X	X	
1.05.005	Vegetation structure -- canopy height by stratum	Habitat structure	X		
1.05.006	Vegetation structure -- canopy volume by stratum	Habitat structure	X		
1.05.007	Vegetation structure -- size-class structure of riparian shrubs & trees	Community / population dynamics, effects of herbivory, habitat structure	X		

Table A-5 continued.

Vital-Sign Category					
ID	**Candidate attributes / <u>measures</u>**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – UPLAND & RIPARIAN COMMUNITIES					
1.05.008	Vegetation structure -- stem density of riparian shrubs & trees	Community / population dynamics, effects of herbivory, habitat structure	X		
1.05.009	Vegetation structure -- age- or size-class structure of key upland shrubs & trees	Community / population dynamics, habitat structure	X		
1.05.010	Vegetation structure -- stem density of key upland shrubs & trees	Community / population dynamics, habitat structure	X		
1.05.011	Vegetation -- frequency of seed production of key forage species	Regeneration potential; effects of herbivory; resilience to drought, herbivory & other disturbances	X		
1.05.012	Vegetation -- ratio of unpalatable to palatable canopy cover	Effects of herbivory on ecosystem / community structure	X		
1.05.013	Vegetation -- annual above-ground production consumed by herbivores	Effects of herbivory on ecosystem function	X		
1.05.014	Vegetation -- abundance of diseased or insect-infested trees	Community / population dynamics, habitat structure / quality	X		
1.05.015	Vegetation -- ratio of exotic to native canopy cover	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	
1.05.016	Invasive exotic plants -- % canopy cover by species	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.05.017	Invasive exotic plants -- spatial distribution by species	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.05.018	Invasive exotic plants -- frequency by species	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X		
1.05.019	Invasive exotic plants -- age- or size-class structure of long-lived woody invaders	Competition with native species, population / community dynamics, habitat quality, potential alteration of ecosystem structure & function	X		
1.05.020	Standing dead trees in forested ecosystems -- abundance	Habitat structure	X		
1.05.021	Downed woody debris in forested ecosystems -- abundance	Habitat structure	X		
1.05.022	Keystone species -- abundance	Biodiversity component, ecosystem functions	X		
1.05.023	Invasive birds -- abundance of brown-headed cowbirds	Competition with native species, habitat quality	X		
1.05.024	Avian pinyon-juniper obligates -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X		X
1.05.025	Avian sagebrush obligates -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X		X
1.05.026	Avian riparian obligates -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X	X	X
1.05.027	Avian aspen-forest obligates -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X		
1.05.028	Resident avifauna -- abundance & diversity	Biodiversity component, prey base, integration with regional conservation & monitoring programs	X		
1.05.029	Avian predators -- abundance & diversity	Biodiversity component, predation, integration with regional conservation & monitoring programs	X		
1.05.030	Standing stock faunal biomass	Prey base	X		

Table A-5 continued.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Ecosystem Structure & Function – UPLAND & RIPARIAN COMMUNITIES					
1.05.031	Small mammals -- abundance & diversity	Biodiversity component, prey base, granivory, herbivory	X		
1.05.032	Native ungulates -- abundance & diversity	Biodiversity component, herbivory, prey base	X		
1.05.033	Mammalian predators -- abundance & diversity	Biodiversity component, predation	X		
1.05.034	Bats -- abundance & diversity	Biodiversity component, integration with regional conservation & monitoring programs	X		X
1.05.035	Reptiles -- abundance & diversity	Biodiversity component, prey base	X		
1.05.036	Invertebrates -- abundance & diversity	Biodiversity component, prey base, other ecosystem functions	X		
1.05.037	Invertebrate pollinators -- abundance & diversity	Biodiversity component, pollination services, prey base	X		
1.05.038	Invertebrate herbivores -- abundance & diversity	Biodiversity component, herbivory, prey base	X		
1.05.039	Soil invertebrates -- abundance & diversity				
1.05.040	Fossorial vertebrates -- abundance & diversity				
1.05.041	Spring / seep / hanging-garden obligates -- abundance & diversity				X
Ecosystem Structure & Function – AQUATIC, RIPARIAN & WETLAND HYDROLOGIC / GEOMORPHIC REGIMES					
1.06.001	Stream flow regime -- continuous flow / discharge variables described by magnitude, frequency, timing, duration, and rate of change	Direct measure of hydrologic regime, major driver of aquatic & riparian ecosystem processes & properties, determinant of channel structure / physical habitat, susceptibility to invasion by exotic species	X	X	X
1.06.002	Degree of departure of current hydrologic regime from historic hydrologic regime, compared on basis of flow variables	Indicates current hydrologic condition in relation to historic	X	X	
1.06.003	Stream stage (gage height) -- continuous measure	Surrogate measure for hydrologic regime	X	X	
1.06.004	Degree of departure of current river-backwater extent from historic	Indicates degree of backwater habitat loss / alteration	X		
1.06.005	Number & duration of dry periods in streams & rivers	Impacts on multiple aquatic & riparian ecosystem processes & properties	X	X	X
1.06.006	Distribution & abundance of beaver dams	Sediment & water retention, physical habitat structure, floodplain formation & maintenance,	X	X	
1.06.007	Channel morphology -- surveyed cross sections (for width:depth ratio & entrenchment ratio)	Energy dissipation, sediment & water retention, physical habitat structure, floodplain formation & maintenance, upland hillslope processes	X	X	X
1.06.008	Channel morphology -- width	Energy dissipation, sediment & water retention, physical habitat structure, floodplain formation & maintenance, upland hillslope processes	X		
1.06.009	Channel morphology -- sinuosity	Energy dissipation, sediment & water retention, physical habitat structure, floodplain formation & maintenance, upland hillslope processes	X		
1.06.010	Channel morphology -- surveyed longitudinal profile / gradient	Sediment transport, habitat structure, channel adjustment	X		
1.06.011	Stream sediment load / transport	Sediment transport, upland hillslope processes, channel adjustment	X		X
1.06.012	Substrate pebble counts	Sediment transport, habitat structure, upland hillslope processes, channel adjustment	X		

Table A-5 continued.

Vital-Sign Category					
ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Ecosystem Structure & Function – AQUATIC, RIPARIAN & WETLAND HYDROLOGIC / GEOMORPHIC REGIMES					
1.06.013	Substrate particle-size distribution	Sediment transport, habitat structure, upland hillslope processes, channel adjustment	X		
1.06.014	Large woody debris -- distribution & abundance	Sediment & water retention, energy dissipation, floodplain development, bank stabilization, channel maintenance, energy & nutrient inputs	X		
1.06.015	Vegetation cover -- % canopy cover by species, longitudinal along streambank	Bank stabilization, sediment retention, channel maintenance, energy & nutrient inputs	X	X	X
1.06.016	Vegetation cover -- % canopy cover by species, cross-sectional across riparian zones & wetlands	Sediment & water retention, energy dissipation, floodplain development, ground-water recharge, channel maintenance, energy & nutrient inputs; indicator of hydrologic regime	X	X	X
1.06.017	Vegetation structure -- size-class structure of riparian shrubs & trees	Recruitment, maintenance / persistence of hydrologic function	X		
1.06.018	Vegetation vigor -- live canopy volume of native riparian trees	Indicator of altered hydrologic regime (floodplain water-table level)	X		
1.06.019	Vegetation -- % cover of tamarisk	Indicator of altered hydrologic regime; competition with native species	X	X	X
1.06.020	Vegetation -- areal extent of wetland vegetation	Indicator of hydrologic regime	X	X	X
1.06.021	Riparian & wetland water-table level in relation to ground-surface elevations	Hydrologic regime, effects of diversions / withdrawals, impacts to wetland / riparian vegetation	X	X	X
1.06.022	Water quantity (flow / discharge) at seeps & springs	Indicator of hydrologic regime	X	X	X
1.06.023	Hanging gardens -- areal extent of wet soil / substrate	Surrogate for flow from seep zones, indicator of hydrologic regime	X		
1.06.024	Stage / level or depth of standing surface water in ponds / rock pools	Indicator of hydrologic regime, water retention	X		
1.06.025	Soil bulk density (compaction measure) in wet / mesic meadows	Infiltration capacity, water retention, ground-water recharge, effects of trampling	X		
1.06.026	Soil penetration resistance (compaction measure) in wet / mesic meadows	Infiltration capacity, water retention, ground-water recharge, effects of trampling	X		
1.06.027	Density of roads & trails within riparian & wetland buffer zones	Sedimentation, hydrologic function	X	X	X
1.06.028	Spatial distribution & abundance of road & trail crossings across riparian & wetland zones	Bank stability, sedimentation, channel morphology, hydrologic function, habitat structure	X	X	X
1.06.029	Groundwater depth in wells pertinent to park groundwater recharge	Hydrologic regime, effects of diversions / withdrawals, impacts to springs / seeps / hanging gardens	X	X	X
1.06.030	Spatial distribution & size of sandy beaches along major rivers				X
Ecosystem Structure & Function – WATER QUALITY					
1.07.001	Temperature	NPS core parameter, impacts multiple ecosystem / physiological processes	X	X	X
1.07.002	pH	NPS core parameter, impacts multiple ecosystem / physiological processes	X	X	X

Table A-5 continued.

ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
Ecosystem Structure & Function – WATER QUALITY					
1.07.003	Dissolved oxygen	NPS core parameter, impacts multiple ecosystem / physiological processes	X	X	X
1.07.004	Specific conductance	NPS core parameter, impacts multiple ecosystem / physiological processes	X	X	X
1.07.005	Flow / discharge (flowing-water body) at time of sample	NPS core parameter, required for interpretation and/or calculation of other parameters	X	X	X
1.07.006	Stage / level (non-flowing water body) at time of sample	NPS core parameter, required for interpretation and/or calculation of other parameters	X	X	X
1.07.007	Common cations & anions	Concentrations affect physiological processes	X		
1.07.008	Alkalinity / acid neutralizing capacity (ANC)	Indicates capacity of water to buffer acidic inputs or processes	X	X	
1.07.009	Total dissolved solids (TDS)	Concentrations affect physiological processes	X		
1.07.010	Total suspended solids (TSS)	Light penetration (water clarity), siltation	X		
1.07.011	Turbidity	Light penetration (water clarity), siltation	X		
1.07.012	Transmissivity	Light penetration (water clarity), siltation	X		
1.07.013	Secchi disk depth	Light penetration (water clarity), siltation	X		
1.07.014	Chlorophyll a	Surrogate indicator of phytoplankton biomass	X		
1.07.015	Biological oxygen demand (BOD)	Indicates levels of organic materials in water	X		
1.07.016	Dissolved organic carbon (DON)	Energy source	X		
1.07.017	Suspended organic carbon (SOC)	Energy source	X		
1.07.018	Nutrients -- nitrogen compounds	Nutrient source, potential system stressor due to enrichment	X	X	
1.07.019	Nutrients -- phosphorus compounds	Nutrient source, potential system stressor due to enrichment	X	X	
1.07.020	Pathogens -- fecal coliforms, periodic sampling	Biological stressor / pollutant	X		
1.07.021	Pathogens -- giardia	Biological stressor / pollutant	X		
1.07.022	Toxics -- metals	Chemical stressor / pollutant	X		
1.07.023	Toxics -- organic compounds	Chemical stressor / pollutant	X		
1.07.024	Radiological contaminants	Radiological stressor / pollutant	X		
1.07.025	Aquatic macroinvertebrates -- abundance & diversity	Integrated indicator of water-quality conditions, food-web component	X	X	
1.07.026	Periphyton -- biomass & diversity	Integrated indicator of water-quality conditions, primary producers, food-web component	X		
1.07.027	Fish -- tissue concentrations of contaminants	Bioaccumulation	X		
Ecosystem Structure & Function – AQUATIC COMMUNITIES					
1.08.001	Periphyton -- biomass & diversity	Biodiversity component, primary producers	X		
1.08.002	Phytoplankton -- biomass & diversity	Biodiversity component, primary producers	X		
1.08.003	Macrophytic aquatic plants -- abundance & diversity	Biodiversity component, primary producers	X		
1.08.004	Macrophytic aquatic plants -- ratio of exotic abundance to native abundance	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X		
1.08.005	Exotic aquatic plants -- abundance & distribution	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X

Table A-5 continued.

ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
Ecosystem Structure & Function – AQUATIC COMMUNITIES					
1.08.006	Aquatic macroinvertebrates -- abundance & diversity	Biodiversity component, food-chain component, multiple ecosystem functions, integration with regional conservation & monitoring programs	X	X	X
1.08.007	Aquatic macroinvertebrates -- ratio of exotic abundance to native abundance	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X		
1.08.008	Exotic aquatic macroinvertebrates (e.g., crayfish) -- abundance & distribution	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.08.009	Amphibians -- abundance & diversity	Biodiversity component, food-chain component, integration with regional conservation & monitoring programs	X	X	X
1.08.010	Amphibians -- ratio of exotic abundance to native abundance	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X		
1.08.011	Exotic amphibians (e.g., bullfrogs) -- abundance & distribution	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.08.012	Fish -- abundance & diversity	Biodiversity component, food-chain component, integration with regional conservation & monitoring programs	X	X	X
1.08.013	Fish -- ratio of exotic abundance to native abundance	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.08.014	Exotic fish -- abundance & distribution	Competition with native species, habitat quality, potential alteration of ecosystem structure & function	X	X	X
1.08.015	Keystone species -- river otters -- abundance & distribution	Biodiversity component, key predator	X		
1.08.016	Keystone species -- beavers -- abundance & distribution	Biodiversity component, key ecosystem / hydrologic engineer, habitat alteration	X	X	
1.08.017	Native aquatic community composition -- degree of departure from historic on basis of compositional similarity	Indicates degree of biotic alteration from historic	X		
1.08.018	Native aquatic community "biotic integrity" -- degree of departure from reference condition on basis of multimetric index	Indicates degree of departure from desired reference condition	X		
1.08.019	Compositional similarity of native aquatic communities in the Green and Yampa Rivers	Indicates degree of departure from natural conditions imposed by Flaming Gorge Dam on Green River	X		
1.08.020	Periphyton community composition -- degree of departure from reference-site benchmark	Indicates degree of departure from desired reference condition			
Ecosystem Structure & Function – LANDSCAPE-LEVEL PATTERNS					
1.09.001	Movement / habitat-use patterns of medium-to-large carnivores on park and adjacent lands	Landscape connectivity, linkages between parks & adjacent lands	X		
1.09.002	Movement / habitat-use patterns of large ungulates on park and adjacent lands	Landscape connectivity, linkages between parks & adjacent lands	X	X	X
1.09.003	Movement / habitat-use patterns of wide-ranging avian predators on park and adjacent lands	Landscape connectivity, linkages between parks & adjacent lands	X		
1.09.004	Compositional similarity of key taxonomic groups among key landscape components or ecosystem types	Landscale-level taxonomic diversity ("beta diversity"), potential indicator of compositional homogenization due to invasive spp. or other factors	X		

Table A-5 continued.

ID	Candidate attributes / <u>measures</u>	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
Ecosystem Structure & Function – LANDSCAPE-LEVEL PATTERNS					
1.09.005	Proportions of park lands categorized by different land-use & land-cover / ecosystem types	Land-use / land-cover trends, landscape-level patch heterogeneity & habitat structure, effects on watershed hydrologic function & water quality	X	X	X
1.09.006	Proportions of adjacent lands categorized by different land-use & land-cover / ecosystem types	Land-use / land-cover trends, landscape-level patch heterogeneity & habitat structure, effects on watershed hydrologic function & water quality	X	X	X
1.09.007	Patch-size distribution of different land-cover / ecosystem types on park lands (a histogram)	Landscape patchiness, fragmentation, invasion susceptibility, microclimatic alteration & other edge effects	X	X	X
1.09.008	Patch-size distribution of different land-cover / ecosystem types on adjacent lands (a histogram)	Landscape patchiness, fragmentation, invasion susceptibility, microclimatic alteration & other edge effects	X		
1.09.009	Spatial distribution of land-cover / ecosystem patches on park lands (a map)	Facilitates assessment & communication of landscape-level patch heterogeneity & habitat structure, patch demography, connectivity	X	X	X
1.09.010	Spatial distribution of land-cover / ecosystem patches on adjacent lands (a map)	Facilitates assessment & communication of landscape-level patch heterogeneity & habitat structure, connectivity, patch demography, potential impacts on park resources	X	X	X
1.09.011	Proportions of park lands in different ecosystem-condition classes defined by degree of departure from desired condition	Aggregate indicator of park ecological condition	X	X	X
1.09.012	Proportions of adjacent lands in different ecosystem-condition classes defined by degree of departure from desired condition	Aggregate indicator of adjacent ecological conditions, potential impacts on park resources	X		X
1.09.013	Spatial distribution of land-cover / ecosystem patches on park lands, classified by ecosystem condition (a map)	Facilitates assessment & communication of landscape-level resource conditions	X	X	X
1.09.014	Spatial distribution of land-cover / ecosystem patches on adjacent lands, classified by ecosystem condition (a map)	Facilitates assessment & communication of landscape-level resource conditions, potential impacts on park resources	X		X
1.09.015	Cross-boundary contrast between park lands and adjacent lands on basis of land use, land cover, and/or ecosystem condition	Park insularization, edge contrast, invasion susceptibility, multiple impacts on within-park ecosystems & populations	X	X	X
1.09.016	Spatial distribution & density of roads on adjacent lands	Watershed hydrologic function & water quality, invasion susceptibility, other potential impacts to park resources	X	X	X
1.09.017	Movement / habitat-use patterns of mountain lions on park and adjacent lands				X
Species / Populations of Concern					
2.01.001	Plants -- Arizona willow (*Salix arizonica*)	Federally protected species	X	X	
2.01.002	Plants -- Despain's cactus (*Pediocactus despaini*)	Federally endangered species	X	X	
2.01.003	Plants -- Jone's cycladenia (*Cycladenia humulis var. jonesii*)	Federally threatened species	X	X	
2.01.004	Plants -- Last Chance townsendia (*Townsendia aprica*)	Federally threatened species	X	X	
2.01.005	Plants -- Maguire daisy (*Erigeron maguirei*)	Federally threatened species	X	X	
2.01.006	Plants -- Shivwits Milkvetch (*Astragalus eremiticus var. ampullarioides*)	Federally endangered species	X	X	
2.01.007	Plants -- Sye's Butte plainsmustard (*Schoenocrambe barnebyi*)	Federally endangered species	X	X	

Table A-5 continued.

ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
Species / Populations of Concern					
2.01.008	Plants -- Ute ladies' tresses (*Spiranthes diluvialis*)	Federally threatened species	X	X	
2.01.009	Plants -- Winkler's pin-cushion cactus (*Pediocactus winkleri*)	Federally threatened species	X	X	
2.01.010	Plants -- Wonderland Alice-flower (*Gilia caespitosa*)	Candidate for federal listing	X	X	
2.01.011	Plants -- Wright fishhook cactus (*Sclerocactus wrightiae*)	Federally endangered species	X	X	
2.01.012	Plants -- Hanging-garden endemic species	Valued endemic taxa	X	X	
2.01.013	Plants -- Other rare and/or endemic species	Valued rare and/or endemic taxa	X	X	
2.01.014	Invertebrates -- Zion snail (*Physa zionis*)	Valued endemic taxon	X	X	
2.01.015	Fish -- Bonytail chub (*Gila elegans*)	Federally endangered species	X	X	
2.01.016	Fish -- Colorado pikeminnow (*Ptychocheilus lucius*)	Federally endangered species	X	X	
2.01.017	Fish -- Humpback chub (*Gila cypha*)	Federally endangered species	X	X	
2.01.018	Fish -- Razorback sucker (*Xyrauchen texanus*)	Federally endangered species	X	X	
2.01.019	Fish -- Virgin spinedace (*Lepidomeda mollispinis*)	Federally protected species	X	X	
2.01.020	Reptiles -- Desert tortoise (*Gopherus agassazii*)	Federally threatened species	X	X	
2.01.021	Amphibian populations -- proportion of area occupied (PAO)	Valued sensitive taxa, potentially declining; focus of nationwide Amphibian Research & Monitoring Initiative which uses PAO measure	X	X	X
2.01.022	Amphibian populations -- frequency of malformations	Valued sensitive taxa, with reported frequencies of deformities that may exceed natural levels	X	X	X
2.01.023	Birds -- American peregrine falcon (*Falco peregrinus anatum*)	Valued species of interest	X	X	X
2.01.024	Birds -- Bald eagle (*Haliaeetus leucocephalus*)	Federally threatened species	X	X	
2.01.025	Birds -- California condor (*Gymnogyps californianus*)	Federally protected species	X	X	
2.01.026	Birds -- Gunnison sage grouse (*Centrocercus minimus*)	Candidate for federal listing	X	X	
2.01.027	Birds -- Mexican spotted owl (*Strix occidentalis lucida*)	Federally threatened species	X	X	X
2.01.028	Birds -- Southwestern willow flycatcher (*Empidonax traillii extimus*)	Federally endangered species	X	X	
2.01.029	Birds -- Yellow-billed cuckoo (*Coccyzus americanus*)	Candidate for federal listing	X	X	
2.01.030	Birds -- Gray vireo (*Viero vicinior*) -- density & productivity	Priority species identified by Utah Partners in Flight, assoc. with pinyon-juniper ecosystems	X	X	
2.01.031	Birds -- Black-throated gray warbler (*Dendroica nigrescens*) -- density & productivity	Priority species identified by Utah Partners in Flight, assoc. with pinyon-juniper ecosystems	X	X	
2.01.032	Birds -- Lucy's warbler (*Vermivora luciae*) -- density & productivity	Priority species identified by Utah Partners in Flight, assoc. with riparian ecosystems	X	X	
2.01.033	Birds -- Lewis woodpecker (*Melanerpes lewis*) -- density & productivity	Priority species identified by Utah Partners in Flight, assoc. with riparian ecosystems	X	X	
2.01.034	Birds -- Golden eagle (*Aquila chrysaetos*)	Valued species of interest	X	X	
2.01.035	Birds -- Western burrowing owl (*Athene cunicularia hypugia*)	Valued species of interest	X	X	
2.01.036	Birds -- Northern goshawk (*Accipiter gentilis*)	Valued species of interest	X	X	
2.01.037	Mammals -- Utah prairie dog (*Cynomys parvidens*)	Federally threatened species	X	X	
2.01.038	Mammals -- Gunnison prairie dog (*Cynomys gunnisoni*)	Valued species of concern	X	X	

Table A-5 continued.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Species / Populations of Concern					
2.01.039	Mammals -- Mountain lions (*Felis concolor*)	Valued species of interest	X	X	
2.01.040	Mammals -- Desert bighorn sheep (*Ovis canadensis nelsoni*)	Valued species of interest	X	X	
2.01.041	Invertebrates -- Other particular species				
Other Natural Resource Values					
3.01.001	Frequency of occurrence & spatial distribution of debris flows in major-river corridors	River-navigation hazards	X		
3.01.002	Spatial distribution & size of sandy beaches along major rivers	Campsite availability	X	X	
3.01.003	Sound levels (in dB) by frequency	Sound intensity, anthropogenic impacts to natural soundscape	X	X	X
3.01.004	Sound sources (recorded audibility data)	Sound identity / source, anthropogenic impacts to natural soundscape	X	X	X
3.01.005	Night sky brightness	Impacts of light pollution on natural night skies	X	X	X
3.01.006	Vegetation -- % canopy cover by species on fossil-bearing substrates	Erosion susceptibility & stability of fossil-bearing substrates, potential impacts to buried fossils from root activity	X		
3.01.007	Changes in surface height of fossil-bearing substrates in relation to benchmark height	Erosion rate of fossil-bearing substrates	X		
3.01.008	Spatial distribution & density of trails & roads in relation to exposures of fossil-bearing substrates	Erosion susceptibility, fossil accessibility	X	X	X
3.01.009	Rates of fossil loss & exposure by erosion on fossil-bearing substrates	Indicate rates of natural fossil loss and exposure	X	X	X
3.01.010	Relative condition of individual fossil-resource sites, defined on basis of natural & anthropogenic risk factors	Site-specific indicator of fossil-resource condition	X	X	X
3.01.011	Cumulative proportions of fossil-bearing surface exposures in different resource-condition classes, defined on basis of natural & anthropogenic risk factors	Overall indicator of fossil-resource condition within a park	X		
3.01.012	Commercial market value of fossils in dollars	Indicates incentive for fossil theft	X		
3.01.013	Amount of published material on fossils in park (total number)	Method of tracking research attributable to pemitted and unpermitted fossil collections	X		
3.01.014	Geologic features (e.g., arches) -- weathering / erosion rates of visited features in relation to comparable controls	Potential impacts of visitation on geologic features	X		
Stressors					
4.01.001	Park use -- park visitation by month (total number of visitors)	Potential impacts to multiple resources	X	X	X
4.01.002	Park use -- terrestrial visitor-use days by location, month & type of activity	Potential impacts to multiple resources	X	X	X
4.01.003	Park use -- watercraft-use days by month & type of watercraft	Potential impacts to multiple resources	X	X	X
4.01.004	Park use -- frequency, location, timing & type of audible overflights	Potential impacts to sensitive wildlife, natural soundscape, wilderness experience	X		
4.01.005	Park use -- frequency, location, timing & type of visible overflights	Potential impacts to wilderness experience	X		
4.01.006	Park use -- frequency of resource theft, poaching, and/or vandalism (total number of documented cases)	Impacts to multiple resources (e.g., wildlife, paleontological resources, rare plants)	X	X	X

Table A-5 continued.

ID	Candidate attributes / measures	Associated processes / functions, or other rationale	In Delphi 2 survey	In pre-workshop survey & workshop	Retained after workshop
Vital-Sign Category					
Stressors					
4.01.007	Park use -- frequency and character of reported human-wildlife interactions	Potential impacts to wildlife resources	X		
4.01.008	Permitted livestock use -- location, timing / duration, and intensity of use	Potential impacts to multiple resources	X	X	X
4.01.009	Permitted livestock use -- location, type, and condition of livestock-related infrastructural developments	Drives distribution of livestock & other animals; potential impacts to water resources, watershed hydrologic function, & associated native communities	X	X	X
4.01.010	Other permitted uses -- location, timing, and type of activity	Potential impacts to multiple resources	X	X	X
4.01.011	Unpermitted livestock use -- frequency, location, timing / duration, and intensity of use	Potential impacts to multiple resources	X	X	X
4.01.012	Other non-compliant uses -- frequency, location, timing / duration, and type of activity	Potential impacts to multiple resources	X	X	X
4.01.013	Feral animals within park -- distribution & abundance by type of animal	Potential impacts to multiple resources	X	X	X
4.01.014	Diseases -- frequency & extent of occurrence within park, by type	Potential impacts to multiple resources	X		
4.01.015	Diseases -- frequency & extent of occurrence within surrounding region, by type	Potential impacts to multiple resources	X	X	X
4.01.016	Park operations -- location, timing & type of new infrastructural development -- NPS & other entities	Potential impacts to multiple resources	X	X	X
4.01.017	Park operations -- location, timing & type of infrastructural maintenance activities (including roads & trails) -- NPS & other entities	Potential impacts to multiple resources	X	X	X
4.01.018	Park operations -- location, timing & type of weed-control activities	Potential impacts to multiple resources	X	X	X
4.01.019	Right-of-way claims (RS2477) -- location & status	Potential impacts to multiple resources	X	X	X
4.01.020	Livestock use on adjacent lands -- location, timing / duration, and intensity of use	Potential impacts to within-park resources, watershed hydrologic function, water quality	X		
4.01.021	Logging activities on adjacent lands -- location / extent, timing and type of operation	Potential impacts to within-park resources, watershed hydrologic function, water quality	X	X	X
4.01.022	Geophysical / mineral exploration and development on adjacent lands -- location / extent, timing and type of operation	Potential impacts to within-park resources, watershed hydrologic function, water quality	X	X	X
4.01.023	Predator-control / hunting activities on adjacent lands (e.g., mountain lions, ungulates, prairie dogs)	Direct mortality, altered predator-prey relationships, altered habitat-use patterns	X		
4.01.024	Pesticide applications -- frequency of occurrence within park airsheds and watersheds, by type of compound	Potential impacts to multiple resources	X	X	X
4.01.025	Downstream & upstream distance of dams	Flow regime change	X	X	X
4.01.026	Upstream & downstream density of water diversions	Reduction of flows or change in baseflow and hydrograph	X	X	X
4.01.027	Permitted water withdrawals from upstream & downstream water diversions (equate to flow reduction)	Reduction of flows or change in baseflow and hydrograph	X	X	X

Table A-5 continued.

Vital-Sign Category					
ID	**Candidate attributes / measures**	**Associated processes / functions, or other rationale**	**In Delphi 2 survey**	**In pre-workshop survey & workshop**	**Retained after workshop**
Stressors					
4.01.028	River regulation / reservoir operation	Change in hydrograph - daily, monthly and yearly	X	X	X
4.01.029	Small impoundments in watershed -- no. of acres	Change in drainage gradient, siltation, establishment of exotics	X	X	X
4.01.030	Groundwater extraction in watershed-irrigation	Threats to springs, seeps, and associated biota	X	X	X
4.01.031	Groundwater extraction in watershed-domestic	Threats to springs, seeps, and associated biota	X		
4.01.032	Groundwater extraction in watershed-municipal	Threats to springs, seeps, and associated biota	X	X	X
4.01.033	Water withdrawals -nonpermitted	Reduction of flows or change in baseflow and hydrograph	X		
4.01.034	Hydropower calls	Rapid fluctuation of flow regime and change in reservoir elevation	X	X	X
4.01.035	Return flows from irrigation	Potential siltation, nutrient inputs, impact to biota	X		
4.01.036	Instream flow rights (lack of recognition)	Continued flow reduction	X		
4.01.037	Flood irrigation management	Dewatering of riverine systems	X		
4.01.038	Calls from downstream senior water rights owners	Maintenance of baseline aside from natural hydrograph	X	X	X
4.01.039	Water exchanges in reservoirs - wet & dry water	Potential to change natural hydrograph	X		
4.01.040	Changes in points of diversion for permitted water withdrawal	Potential to change natural hydrograph	X	X	X
4.01.041	Changes in types of beneficial use - irrigation, municipal, domestic, wildlife	Potential to change natural hydrograph	X	X	X
4.01.042	Changes in type of water right - diversion versus storage	Potential to change natural hydrograph	X	X	X
			310	164	126

Table A-12. Consensus evaluation scores for candidate attributes and measures considered during the NCPN vital-signs workshop held during April 2003. Cells without scores indicate attributes or measures that were not evaluated numerically. Measures and attributes are sorted within categories on the basis of their total weighted evaluation scores (far-right column). See Table A-9 for details concerning individual evaluation criteria.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria): Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs			Total Weighted Scores (weight per category, in percent)					
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3	Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
Ecosystem Structure & Function – CLIMATE																				
1.01.004	Precipitation -- amount per day	1.0	4.4	2.2	4.6	4.4	4.0	3.1	4.9	4.9	5.0	4.9	4.9	4.9	21.3	27.0	19.5	10.0	0.0	77.8
1.01.001	Air temperature -- daily maximum & minimum	1.0	4.4	1.8	4.3	4.1	4.4	3.6	4.4	5.0	5.0	4.9	4.9	5.0	20.0	28.3	17.8	10.0	0.0	76.0
1.01.006	Precipitation events -- frequency, magnitude, and duration	1.0	4.1	2.3	4.3	4.0	4.0	4.0	4.0	4.0	5.0	3.0	3.0	4.7	20.5	28.0	16.0	10.0	0.0	74.5
1.01.005	Precipitation -- form (rain vs. snow)	1.0	3.0	2.0	3.8	4.0	2.6	3.5	4.0	4.8	5.0	4.0	4.5	4.3	17.2	23.5	16.0	10.0	0.0	66.7
1.01.012	Wind events -- frequency, magnitude, and duration	1.0	3.5	3.0	3.8	4.0	3.0	3.0	3.3	4.0	5.0	2.9	2.5	2.5	19.7	23.3	13.3	10.0	0.0	66.4
1.01.015	Plant phenology (date of "green-up," flowering, or other life-history events)	1.3	3.3	1.9	3.3	3.6	2.7	3.1	3.6	4.8	2.5	1.2	1.9	1.8	17.1	21.8	14.5	5.0	0.0	58.4
Ecosystem Structure & Function – AIR QUALITY																				
1.02.001	Nitrogen compounds -- atmospheric deposition	4.1	4.0	2.9	3.6	3.9	3.2	4.0	3.0	3.3	3.9	3.1	2.5	2.3	25.5	25.9	12.0	7.7	0.0	71.1
1.02.008	Particulates -- atmospheric concentrations	4.1	4.1	2.7	3.8	3.6	2.3	2.9	3.3	4.8	3.3	2.6	4.0	3.6	25.8	20.5	13.2	6.5	0.0	65.9
1.02.009	Visibility -- visual range	4.2	4.4	2.9	4.0	2.9	1.8	2.4	3.3	4.8	3.0	2.3	3.6	2.5	27.1	16.5	13.2	6.0	0.0	62.7
1.02.010	Visibility -- light extinction	4.2	4.4	2.9	4.0	2.7	2.2	2.4	2.6	4.8	3.5	2.8	3.7	3.1	27.1	17.0	10.2	6.9	0.0	61.2
1.02.007	Ozone -- atmospheric concentrations	3.8	3.5	1.5	3.6	3.5	2.3	3.1	2.9	4.8	3.6	3.1	3.1	2.9	21.7	20.8	11.6	7.1	0.0	61.1
1.02.002	Sulfur compounds -- atmospheric deposition	4.2	3.8	2.2	3.0	3.3	1.9	3.0	2.7	4.8	3.7	2.4	3.1	2.8	23.0	19.2	10.7	7.3	0.0	60.2
1.02.012	Dust storm frequency & duration	1.7	3.4	2.6	3.9	3.9	2.7	3.1	3.0	4.4	2.6	0.8	1.5	2.8	20.3	22.7	12.0	5.3	0.0	60.2
1.02.013	Dust storm intensity (dust flux measurement)	1.0	3.2	2.4	3.7	3.5	2.9	3.0	2.7	3.9	3.1	0.8	1.8	2.0	18.1	21.9	10.7	6.2	0.0	56.9
1.02.011	Visibility -- deciview	4.2	4.4	2.9	4.0	2.3	1.5	2.0	2.3	5.0	3.3	1.7	1.5	1.3	27.1	13.6	9.3	6.7	0.0	56.6
1.02.017	Surface water chemistry (pH, nutrient & toxin concentrations, acid neutralizing capacity)	1.4	4.0	2.8	3.7	3.0	3.0	3.0	2.0	5.0	3.1	2.0	2.0	2.0	20.8	21.0	8.0	6.3	0.0	56.0
1.02.004	Major cations & anions -- atmospheric deposition	3.7	3.6	1.4	2.7	3.2	1.9	3.1	2.7	4.8	3.1	1.4	3.1	2.8	19.9	19.2	10.7	6.2	0.0	56.0

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria)													Total Weighted Scores (weight per category, in percent)					
		Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs								
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3	Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
Ecosystem Structure & Function – AIR QUALITY																				
1.02.014	Ozone-sensitive plants -- foliar injury, physiological performance	2.0	3.0	2.5	3.0	3.3	2.4	2.9	2.3	3.5	3.0	1.1	2.0	1.3	18.4	19.9	9.0	6.0	0.0	53.2
Ecosystem Structure & Function – UPLAND SOIL & WATER RESOURCES																				
1.03.001	Spatial distribution & density of trails	2.3	4.8	4.5	4.2	4.0	4.0	4.0	4.1	4.5	4.2	3.0	1.2	1.3	27.8	28.0	16.2	8.5	0.0	80.5
1.03.007	Biological soil crust cover & composition -- % cover by morphological group	1.6	4.4	4.5	4.1	4.5	4.4	4.0	3.8	3.0	3.7	2.2	1.8	1.7	25.5	30.0	15.2	7.5	0.0	78.1
1.03.004	Spatial distribution & density of roads	1.9	3.6	3.7	4.1	4.0	4.0	4.0	4.6	4.7	4.1	3.4	2.3	2.2	23.3	28.0	18.4	8.2	0.0	77.9
1.03.003	Spatial extent of soil disturbance associated with trailheads, campgrounds, and other high-use areas	2.2	4.6	4.4	4.1	4.0	4.0	4.0	3.7	4.5	3.9	2.7	1.2	1.4	26.7	28.0	14.9	7.8	0.0	77.4
1.03.013	Vegetation cover & composition -- % canopy cover by species	2.6	4.4	4.0	4.0	4.3	4.2	3.4	3.7	4.1	3.6	3.2	1.9	1.8	26.3	27.9	14.7	7.2	0.0	76.1
1.03.006	Soil aggregate stability -- field index	2.0	4.2	3.7	3.8	4.2	4.2	4.1	3.6	2.7	3.7	0.4	1.6	1.5	24.0	29.1	14.4	7.3	0.0	74.8
1.03.011	Bare soil -- % cover	1.2	3.8	3.5	3.8	4.0	4.0	4.0	4.1	4.5	3.1	3.1	1.6	1.6	21.5	28.0	16.4	6.2	0.0	72.1
1.03.030	Soil penetration resistance (compaction measure)	1.6	4.2	3.7	3.5	3.6	3.5	2.9	3.8	3.3	3.4	1.1	1.1	1.3	22.7	23.5	15.3	6.8	0.0	68.3
1.03.009	Litter -- % cover	1.7	3.1	2.6	2.8	4.0	4.0	4.0	4.0	3.5	2.6	3.4	1.6	2.3	17.8	28.0	16.0	5.2	0.0	67.1
1.03.042	Number, distribution, and condition / spatial extent of backcountry campsites	1.9	3.8	4.0	4.1	2.9	2.6	2.5	3.6	3.8	3.5	2.4	2.1	2.4	24.2	18.8	14.4	6.9	0.0	64.3
1.03.033	Changes in soil-surface height from benchmark																			
1.03.035	Soil movement / accumulation due to fluvial processes (e.g., deposition behind silt fences or natural sediment traps)																			
1.03.043	Soil movement / accumulation due to aeolian processes -- dust traps																			
Ecosystem Structure & Function – UPLAND DISTURBANCE REGIMES																				
1.04.005	Fire occurrence on park lands -- frequency, spatial patterning, intensity, and timing	2.5	4.1	3.1	4.2	4.1	4.0	4.0	4.1	4.5	3.7	3.3	3.8	3.6	24.1	28.2	16.3	7.4	0.0	76.0

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria)													Total Weighted Scores (weight per category, in percent)					
		Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs								
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3	Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
Ecosystem Structure & Function – UPLAND DISTURBANCE REGIMES																				
1.04.011	Fire management / suppression activities on park lands	2.3	4.0	2.9	3.9	4.0	4.0	4.0	3.4	4.4	2.9	3.2	2.6	2.2	22.9	28.0	13.4	5.8	0.0	70.2
1.04.002	Fine surface fuels -- ratio of exotic cover to native cover	2.2	3.5	3.3	3.5	3.7	3.5	3.6	3.0	4.4	2.8	1.3	1.8	2.3	21.9	25.1	12.0	5.5	0.0	64.5
1.04.007	Proportions of park lands in different "fire regime current-condition classes"	2.2	3.6	2.8	4.0	3.6	3.4	3.3	3.1	4.4	2.3	2.3	3.2	2.8	21.9	23.9	12.3	4.7	0.0	62.8
1.04.006	Fire occurrence on adjacent lands -- frequency, spatial patterning, intensity, and timing	1.9	3.7	2.5	4.0	3.5	2.5	2.3	3.5	4.6	3.4	0.6	3.5	3.6	21.2	19.4	14.0	6.8	0.0	61.3
1.04.001	Fine surface fuels -- distribution, cover and spatial continuity	1.9	3.6	2.9	3.6	3.3	2.9	3.2	2.6	4.3	2.4	1.4	2.1	2.1	20.8	22.0	10.2	4.9	0.0	58.0
1.04.009	Spatial distribution of fire regime current-condition classes on park lands (a map)	2.1	2.9	2.6	3.4	2.8	2.7	2.4	2.7	4.4	2.3	1.4	2.8	2.8	19.3	18.4	10.7	4.7	0.0	53.0
1.04.010	Spatial distribution of fire regime current-condition classes on adjacent lands (a map)	1.7	3.5	2.4	3.3	2.8	2.6	2.8	2.4	4.5	2.4	1.0	3.3	3.0	19.0	19.0	9.5	4.8	0.0	52.2
1.04.013	Vegetation -- distribution & abundance of diseased or insect-infested trees in woodland / forest ecosystems																			
1.04.014	Vegetation -- ratio of insect-infected to uninfected trees in woodland / forest ecosystems																			
1.04.015	Vegetation -- distribution & abundance of drought-killed trees in woodland / forest ecosystems																			
Ecosystem Structure & Function – UPLAND & RIPARIAN COMMUNITIES																				
1.05.015	Vegetation -- ratio of exotic to native canopy cover	4.0	4.6	4.3	4.4	4.6	3.9	3.3	3.7	4.3	3.7	2.7	1.7	1.6	30.2	27.5	14.9	7.3	0.0	79.9
1.05.016	Invasive exotic plants -- % canopy cover by species	4.0	4.6	4.0	4.3	4.2	3.9	3.1	3.6	4.5	3.9	2.9	1.7	1.9	29.5	26.0	14.5	7.8	0.0	77.8

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria)													Total Weighted Scores (weight per category, in percent)					
		Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs								
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3	Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
Ecosystem Structure & Function – UPLAND & RIPARIAN COMMUNITIES																				
1.05.017	Invasive exotic plants -- spatial distribution by species	4.0	4.7	4.1	4.4	4.2	3.8	2.9	3.4	4.6	3.7	2.5	2.1	2.6	30.0	25.5	13.6	7.3	0.0	76.4
1.05.003	Vegetation cover & composition -- % canopy cover by species	1.5	4.4	3.6	4.0	4.5	4.2	3.6	3.3	4.5	3.6	2.6	2.9	2.7	23.6	28.6	13.3	7.2	0.0	72.8
1.05.002	Biological soil crust cover & composition -- % cover by morphological group	1.7	4.2	3.8	3.9	4.0	4.0	3.7	3.6	3.2	3.4	2.3	1.6	1.7	23.8	27.3	14.3	6.8	0.0	72.2
1.05.026	Avian riparian obligates -- abundance & diversity	4.0	4.3	3.2	4.0	3.9	2.2	2.5	3.4	4.6	2.6	2.8	3.6	3.5	27.2	20.1	13.5	5.2	0.0	66.1
1.05.004	Vegetation composition -- frequency by species	2.0	4.1	3.4	3.6	3.8	3.5	2.9	3.1	4.5	3.5	2.7	2.8	2.8	22.8	23.8	12.4	6.9	0.0	65.8
1.05.024	Avian pinyon-juniper obligates -- abundance & diversity																			
1.05.025	Avian sagebrush obligates -- abundance & diversity																			
1.05.034	Bats -- abundance & diversity																			
1.05.041	Spring / seep / hanging-garden obligates -- abundance & diversity																			
Ecosystem Structure & Function – AQUATIC, RIPARIAN & WETLAND HYDROLOGIC / GEOMORPHIC REGIMES																				
1.06.020	Vegetation -- areal extent of wetland vegetation	4.0	4.4	3.7	4.4	4.6	4.1	4.1	3.7	4.8	3.3	2.6	1.3	1.9	28.9	30.0	14.8	6.6	0.0	80.3
1.06.001	Stream flow regime -- continuous flow / discharge variables described by magnitude, frequency, timing, duration, and rate of change	4.0	4.7	3.1	4.7	4.8	4.1	3.5	3.8	4.4	3.5	2.4	2.5	2.6	28.9	28.9	15.2	7.1	0.0	80.1
1.06.022	Water quantity (flow / discharge) at seeps & springs	4.0	4.3	3.3	4.3	4.5	4.0	3.8	3.2	4.2	3.1	2.2	1.4	1.1	27.9	28.6	12.8	6.3	0.0	75.6
1.06.015	Vegetation cover -- % canopy cover by species, longitudinal along streambank	1.6	4.5	3.6	4.0	4.4	4.1	4.0	3.9	4.9	3.1	3.2	0.8	1.2	24.0	29.0	15.7	6.3	0.0	75.0
1.06.021	Riparian & wetland water-table level in relation to ground-surface elevations	4.0	4.2	3.6	3.9	4.3	4.0	3.7	3.3	3.4	3.0	1.1	0.9	1.0	27.5	28.0	13.2	6.0	0.0	74.7

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria)													Total Weighted Scores (weight per category, in percent)					
		Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs								
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3	Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
Ecosystem Structure & Function – UPLAND & RIPARIAN COMMUNITIES																				
1.06.007	Channel morphology -- surveyed cross sections (for width:depth ratio & entrenchment ratio)	4.0	3.9	3.3	4.1	3.9	3.8	4.0	3.2	4.5	3.1	2.4	2.4	1.1	26.8	27.3	12.8	6.1	0.0	73.1
1.06.027	Density of roads & trails within riparian & wetland buffer zones	1.5	4.2	4.2	4.0	3.3	3.4	3.1	4.0	4.7	4.6	1.5	1.6	1.6	24.4	22.8	16.0	9.3	0.0	72.6
1.06.019	Vegetation -- % cover of tamarisk	2.2	4.4	3.7	4.1	4.2	3.5	3.7	3.7	4.8	3.2	2.7	2.4	1.6	25.1	26.4	14.6	6.4	0.0	72.4
1.06.028	Spatial distribution & abundance of road & trail crossings across riparian & wetland zones	1.6	4.0	3.7	3.9	3.0	3.6	3.0	4.2	4.7	4.7	1.5	1.5	1.7	23.1	22.5	16.8	9.3	0.0	71.7
1.06.016	Vegetation cover -- % canopy cover by species, cross-sectional across riparian zones & wetlands	0.8	4.3	3.5	3.9	4.1	3.8	3.8	3.8	4.4	3.2	2.9	0.9	0.9	21.7	27.3	15.2	6.4	0.0	70.6
1.06.005	Number & duration of dry periods in streams & rivers	4.0	3.6	2.5	3.2	3.9	2.9	3.2	2.9	4.4	1.9	0.4	1.3	1.3	23.3	23.5	11.5	3.9	0.0	62.1
1.06.029	Groundwater depth in wells pertinent to park groundwater recharge	1.3	3.5	2.6	2.9	3.8	3.6	3.6	2.0	3.7	3.1	0.6	1.2	1.5	18.1	25.6	8.0	6.3	0.0	58.0
1.06.006	Distribution & abundance of beaver dams	1.2	2.9	2.2	3.2	3.3	2.7	3.0	3.5	4.6	2.0	0.3	0.4	0.5	16.6	21.0	14.2	4.0	0.0	55.7
1.06.011	Stream sediment load / transport																			
1.06.030	Spatial distribution & size of sandy beaches along major rivers																			
Ecosystem Structure & Function – WATER QUALITY																				
1.07.002	pH	3.3	4.9	4.1	4.6	4.6	4.2	4.1	4.7	4.9	3.6	4.8	4.4	4.5	29.7	30.1	18.9	7.1	0.0	85.8
1.07.005	Flow / discharge (flowing-water body) at time of sample	3.0	4.7	3.3	4.8	4.8	4.2	4.6	3.9	4.5	3.7	4.5	2.9	3.0	27.4	31.8	15.7	7.3	0.0	82.3
1.07.003	Dissolved oxygen	3.3	4.8	3.6	4.3	4.4	3.6	4.1	4.6	4.9	3.7	4.7	3.7	3.8	27.9	28.0	18.6	7.5	0.0	82.0
1.07.001	Temperature	3.2	4.5	3.3	3.9	4.1	3.8	4.3	4.7	4.9	3.8	4.8	4.7	4.8	26.0	28.4	18.9	7.6	0.0	81.0
1.07.004	Specific conductance	2.9	4.5	3.7	4.4	4.1	3.5	3.6	4.6	4.9	3.6	4.7	3.6	3.8	27.0	26.1	18.6	7.3	0.0	78.9
1.07.018	Nutrients -- nitrogen compounds	3.1	4.7	4.0	4.5	4.4	3.8	4.3	2.9	4.9	3.7	4.2	2.5	2.6	28.5	29.2	11.7	7.3	0.0	76.7
1.07.008	Alkalinity / acid neutralizing capacity (ANC)	2.3	3.8	3.6	4.2	3.5	3.7	4.1	3.5	4.7	3.9	4.0	2.0	2.5	24.2	26.3	13.8	7.8	0.0	72.2
1.07.006	Stage / level (non-flowing water body) at time of sample	2.4	4.3	2.8	4.3	3.8	2.8	4.4	4.0	4.2	3.0	3.8	2.3	4.5	24.3	25.7	16.0	6.0	0.0	72.0
1.07.019	Nutrients -- phosphorus compounds	3.1	4.7	3.3	4.1	4.2	3.4	3.9	2.8	4.9	3.5	4.2	2.3	2.4	26.4	26.9	11.0	7.0	0.0	71.3

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria) Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs			Total Weighted Scores (weight per category, in percent) Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3						
Ecosystem Structure & Function — WATER QUALITY																				
1.07.025	Aquatic macroinvertebrates -- abundance & diversity	1.3	4.7	4.0	3.8	4.3	4.1	3.1	3.2	2.6	3.1	3.2	1.8	1.6	24.0	26.8	12.9	6.2	0.0	69.8
Ecosystem Structure & Function – AQUATIC COMMUNITIES																				
1.08.014	Exotic fish -- abundance & distribution	4.0	4.2	3.6	4.1	4.3	3.5	3.6	2.9	2.7	2.9	3.5	3.5	3.2	27.9	26.4	11.7	5.9	0.0	71.8
1.08.005	Exotic aquatic plants -- abundance & distribution	4.0	3.6	2.8	3.6	4.0	3.3	3.9	3.4	4.3	3.0	0.5	0.3	0.9	24.5	26.0	13.5	6.0	0.0	70.0
1.08.013	Fish -- ratio of exotic abundance to native abundance	4.0	3.7	3.6	4.1	4.1	3.6	3.3	2.7	2.9	2.8	3.0	2.9	2.7	27.1	25.5	10.9	5.6	0.0	69.1
1.08.008	Exotic aquatic macroinvertebrates (e.g., crayfish) -- abundance & distribution	4.0	3.6	2.9	4.0	3.7	3.4	3.6	2.8	2.8	3.1	0.6	1.0	0.9	25.4	24.9	11.1	6.2	0.0	67.6
1.08.011	Exotic amphibians (e.g., bullfrogs) -- abundance & distribution	4.0	3.4	4.0	4.2	3.4	2.9	2.6	3.1	4.3	3.1	1.0	1.0	0.8	27.3	20.7	12.4	6.2	0.0	66.6
1.08.012	Fish -- abundance & diversity	2.5	3.7	3.3	4.3	4.5	3.8	3.5	2.6	3.1	2.2	3.1	3.0	3.0	24.1	27.4	10.6	4.4	0.0	66.4
1.08.009	Amphibians -- abundance & diversity	2.9	4.0	2.8	3.6	3.9	3.5	3.4	2.9	3.8	2.6	3.3	1.7	1.3	23.4	25.2	11.4	5.3	0.0	65.2
1.08.006	Aquatic macroinvertebrates -- abundance & diversity	0.9	4.2	3.2	3.7	4.1	3.3	4.0	2.6	2.8	2.4	2.4	2.3	1.9	21.0	26.5	10.5	4.9	0.0	62.9
1.08.016	Keystone species -- beavers -- abundance & distribution	1.7	3.0	2.4	3.1	3.5	3.3	3.2	3.7	4.6	3.2	0.5	0.6	0.3	17.7	23.3	14.8	6.5	0.0	62.3
Ecosystem Structure & Function – LANDSCAPE-LEVEL PATTERNS																				
1.09.016	Spatial distribution & density of roads on adjacent lands	1.4	4.2	3.2	3.8	4.2	3.4	3.9	4.2	4.8	4.6	0.9	2.2	2.1	22.1	26.9	16.9	9.2	0.0	75.2
1.09.015	Cross-boundary contrast between park lands and adjacent lands on basis of land use, land cover, and/or ecosystem condition	2.3	4.4	4.0	4.5	4.2	4.1	3.7	2.9	4.5	3.9	2.5	1.4	1.3	26.6	28.0	11.4	7.9	0.0	73.8
1.09.011	Proportions of park lands in different ecosystem-condition classes defined by degree of departure from desired condition	2.0	4.5	3.6	3.7	3.9	4.0	4.1	3.1	4.6	4.2	0.6	1.3	1.2	24.2	28.0	12.3	8.4	0.0	72.9
1.09.009	Spatial distribution of land-cover / ecosystem patches on park lands (a map)	2.6	4.4	3.2	4.1	4.4	3.8	3.4	3.0	4.6	3.4	2.7	2.6	2.3	25.1	27.2	12.0	6.8	0.0	71.1

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria)													Total Weighted Scores (weight per category, in percent)					
		Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs								
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3	Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
Ecosystem Structure & Function– LANDSCAPE-LEVEL PATTERNS																				
1.09.013	Spatial distribution of land-cover / ecosystem patches on park lands, classified by ecosystem condition (a map)	1.5	4.5	3.8	4.1	4.3	4.1	3.8	2.8	4.6	3.4	1.3	2.0	1.9	24.3	28.5	11.2	6.8	0.0	70.8
1.09.006	Proportions of adjacent lands categorized by different land-use & land-cover / ecosystem types	1.3	4.4	3.1	4.0	4.2	3.8	3.8	3.0	4.6	3.8	2.1	2.9	2.5	22.3	27.5	12.0	7.6	0.0	69.4
1.09.010	Spatial distribution of land-cover / ecosystem patches on adjacent lands (a map)	1.6	4.4	3.1	4.2	4.2	3.8	3.4	3.0	4.6	3.6	1.6	2.6	2.5	23.3	26.7	12.0	7.2	0.0	69.2
1.09.005	Proportions of park lands categorized by different land-use & land-cover / ecosystem types	2.0	4.3	3.2	4.3	3.4	3.4	2.8	3.0	4.4	3.5	2.8	2.2	2.1	24.2	22.5	12.0	7.0	0.0	65.7
1.09.007	Patch-size distribution of different land-cover / ecosystem types on park lands (a histogram)	1.1	4.3	3.0	3.6	3.9	3.7	3.3	3.0	4.8	3.3	1.2	1.9	1.7	20.9	25.5	12.0	6.5	0.0	64.8
1.09.002	Movement / habitat-use patterns of large ungulates on park and adjacent lands	1.3	3.9	2.6	3.8	3.6	4.0	4.0	2.5	4.6	2.5	0.6	4.0	2.3	20.2	27.1	10.0	5.0	0.0	62.3
1.09.012	Proportions of adjacent lands in different ecosystem-condition classes defined by degree of departure from desired condition																			
1.09.014	Spatial distribution of land-cover / ecosystem patches on adjacent lands, classified by ecosystem condition (a map)																			
1.09.017	Movement / habitat-use patterns of mountain lions on park and adjacent lands																			
Species / Populations of Concern																				
2.01.012	Plants -- Hanging-garden endemic species	1.7	4.5	3.9	4.1	4.0	3.9	3.7	3.6	3.6	3.8	2.0	1.3	1.6	24.8	27.2	14.6	7.6	0.0	74.2

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria): Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs			Total Weighted Scores (weight per category, in percent)					
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3	Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
Species / Populations of Concern																				
2.01.027	Birds -- Mexican spotted owl (*Strix occidentalis lucida*)	4.3	4.3	3.0	3.8	3.9	3.0	3.0	3.7	4.2	3.7	3.7	4.1	3.0	27.0	23.1	14.8	7.4	0.0	72.2
2.01.023	Birds -- American peregrine falcon (*Falco peregrinus anatum*)	4.4	4.7	3.8	4.1	3.2	3.0	2.3	3.7	4.8	3.9	4.7	4.7	4.7	29.8	19.9	14.7	7.8	0.0	72.2
2.01.021	Amphibian populations -- proportion of area occupied (PAO)	1.9	3.7	3.6	4.0	3.9	3.7	3.3	2.8	3.9	3.2	2.9	1.6	1.4	23.1	25.3	11.2	6.4	0.0	66.0
2.01.022	Amphibian populations -- frequency of malformations	2.7	4.6	3.6	4.2	3.6	3.0	1.8	2.8	3.7	3.2	0.8	1.1	1.0	26.2	19.6	11.3	6.4	0.0	63.4
Other Natural Resource Values																				
3.01.008	Spatial distribution & density of trails & roads in relation to exposures of fossil-bearing substrates	2.3	3.9	4.3	4.3	3.9	3.6	4.2	4.2	4.8	4.6	1.2	1.1	1.1	25.9	27.2	16.9	9.1	0.0	79.1
3.01.010	Relative condition of individual fossil-resource sites, defined on basis of natural & anthropogenic risk factors	3.1	3.9	4.0	4.0	3.9	3.6	3.9	3.3	4.3	4.1	1.0	0.8	0.8	26.3	26.6	13.0	8.3	0.0	74.1
3.01.005	Night sky brightness	2.2	4.4	3.9	4.5	3.4	2.5	3.0	3.8	4.9	4.4	2.2	1.3	1.2	26.3	20.7	15.2	8.7	0.0	70.8
3.01.003	Sound levels (in dB) by frequency	2.3	4.1	4.1	4.1	3.3	2.4	2.4	3.4	4.9	4.5	3.1	1.8	1.8	25.5	19.0	13.7	9.0	0.0	67.2
3.01.004	Sound sources (recorded audibility data)	1.8	4.4	3.9	4.1	2.9	2.5	2.4	3.5	4.9	4.2	1.8	1.9	1.8	24.7	18.2	14.0	8.4	0.0	65.3
3.01.009	Rates of fossil loss & exposure by erosion on fossil-bearing substrates	2.3	3.3	3.3	3.5	3.0	3.0	3.1	2.6	4.8	4.1	0.5	0.8	0.8	21.4	21.3	10.5	8.3	0.0	61.5
3.01.002	Spatial distribution & size of sandy beaches along major rivers	1.7	3.4	2.5	2.9	3.1	2.9	2.4	2.9	4.8	3.6	2.0	2.0	2.0	18.3	19.6	11.5	7.3	0.0	56.7
Stressors																				
4.01.008	Permitted livestock use -- location, timing / duration, and intensity of use	3.3	4.5	4.9	4.4	4.6	4.6	4.0	3.9	4.6	4.3	3.9	4.1	4.6	29.8	30.8	15.5	8.5	0.0	84.7
4.01.001	Park use -- park visitation by month (total number of visitors)	3.2	4.7	4.5	4.5	3.9	3.5	3.5	4.5	4.9	4.6	3.1	1.4	3.4	29.5	25.2	18.0	9.3	0.0	82.0
4.01.018	Park operations -- location, timing & type of weed-control activities	2.9	4.0	3.9	3.9	4.0	4.0	4.0	4.4	4.8	4.4	3.6	1.6	2.4	25.9	28.0	17.7	8.7	0.0	80.3

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria) — Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs			Total Weighted Scores (weight per category, in percent)					
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3	Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
Stressors																				
4.01.017	Park operations -- location, timing & type of infrastructural maintenance activities (including roads & trails) -- NPS & other entities	3.3	4.3	4.3	4.1	4.1	3.3	3.7	3.7	4.4	4.4	2.4	3.3	3.6	28.1	26.1	14.8	8.9	0.0	77.9
4.01.002	Park use -- terrestrial visitor-use days by location, month & type of activity	2.0	4.6	4.4	4.1	4.0	4.0	4.0	3.6	4.7	4.5	1.0	2.0	3.3	26.4	28.0	14.4	9.0	0.0	77.8
4.01.011	Unpermitted livestock use -- frequency, location, timing / duration, and intensity of use	2.7	4.7	4.3	4.3	4.0	4.0	4.0	3.1	4.6	4.6	1.2	1.2	1.3	28.0	28.0	12.2	9.1	0.0	77.4
4.01.009	Permitted livestock use -- location, type, and condition of livestock-related infrastructural developments	2.0	3.8	3.9	4.0	4.0	4.0	5.0	3.6	4.8	4.1	2.3	3.4	3.6	23.8	30.3	14.5	8.3	0.0	76.9
4.01.010	Other permitted uses -- location, timing, and type of activity	3.3	3.8	3.8	4.0	3.6	3.6	3.3	4.3	4.8	4.3	2.4	1.4	2.0	26.1	24.2	17.3	8.5	0.0	76.1
4.01.016	Park operations -- location, timing & type of new infrastructural development -- NPS & other entities	2.2	4.5	4.0	4.0	4.0	4.0	4.0	3.2	4.5	4.3	1.4	3.0	2.4	25.6	28.0	12.8	8.6	0.0	75.0
4.01.026	Upstream & downstream density of water diversions	4.0	4.3	3.0	4.1	4.1	3.0	3.7	3.9	4.6	3.6	1.9	3.3	2.7	27.0	25.2	15.6	7.1	0.0	74.9
4.01.019	Right-of-way claims (RS2477) -- location & status	3.4	4.6	3.6	4.3	3.0	3.0	3.0	4.2	4.5	4.7	1.8	1.8	2.3	27.6	21.0	16.7	9.3	0.0	74.6
4.01.028	River regulation / reservoir operation	4.0	4.4	3.7	3.5	4.4	3.0	3.3	3.4	4.9	4.0	1.5	2.6	2.2	27.3	25.0	13.6	8.0	0.0	73.9
4.01.034	Hydropower calls	4.0	4.8	2.8	3.3	4.3	1.5	3.3	4.8	4.3	3.0	1.3	3.5	3.0	25.8	21.0	19.0	6.0	0.0	71.8
4.01.032	Groundwater extraction in watershed-municipal	4.0	3.8	3.5	3.5	3.6	3.4	3.3	3.9	4.5	2.9	1.0	0.8	1.0	25.9	24.0	15.6	5.8	0.0	71.3
4.01.022	Geophysical / mineral exploration and development on adjacent lands -- location / extent, timing and type of operation	2.9	3.9	3.2	3.8	3.3	3.1	3.5	3.8	4.8	4.4	3.1	4.6	4.6	24.2	23.2	15.1	8.8	0.0	71.3

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria)													Total Weighted Scores (weight per category, in percent)					
		Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs								
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	4.1	5.1	5.2	5.3	Mgmt. Signif. (35)	Ecol. Signif. (35)	Feas. & Cost (20)	Varia-bility (10)	Existing Data (0)	Total Score (100)
Stressors																				
4.01.027	Permitted water withdrawals from upstream & downstream water diversions (equate to flow reduction)	4.0	4.4	1.9	3.3	3.9	3.5	3.6	3.6	4.8	3.5	1.6	3.3	3.1	23.6	25.7	14.5	7.0	0.0	70.9
4.01.024	Pesticide applications -- frequency of occurrence within park airsheds and watersheds, by type of compound	3.3	4.3	3.2	3.6	3.6	2.8	3.5	3.5	4.8	3.9	2.0	2.1	2.4	25.4	23.1	14.2	7.7	0.0	70.3
4.01.021	Logging activities on adjacent lands -- location / extent, timing and type of operation	2.1	4.1	3.2	4.1	3.8	3.4	3.6	2.9	4.5	4.0	0.8	3.9	3.4	23.6	25.2	11.6	8.0	0.0	68.4
4.01.029	Small impoundments in watershed -- no. of acres	4.0	3.7	3.2	3.3	4.0	3.3	2.7	3.2	4.8	3.7	1.0	2.3	3.0	24.8	23.3	12.7	7.3	0.0	68.2
4.01.030	Groundwater extraction in watershed-irrigation	4.0	3.6	3.3	3.4	3.6	3.6	3.5	2.7	4.5	3.5	0.6	1.3	1.5	25.0	25.0	10.7	7.0	0.0	67.7
4.01.006	Park use -- frequency of resource theft, poaching, and/or vandalism (total number of documented cases)	3.1	4.6	4.2	4.5	3.2	2.4	2.2	3.2	4.8	4.0	2.2	1.8	2.2	28.7	18.2	12.6	8.0	0.0	67.5
4.01.025	Downstream & upstream distance of dams	4.0	3.3	2.3	3.8	3.7	1.8	2.2	4.5	4.8	3.3	2.8	4.3	4.5	23.6	17.9	18.0	6.7	0.0	66.2
4.01.012	Other non-compliant uses -- frequency, location, timing / duration, and type of activity	2.4	4.3	3.4	3.8	3.5	3.2	3.3	2.6	4.6	3.9	1.6	1.3	1.7	24.4	23.2	10.3	7.8	0.0	65.8
4.01.038	Calls from downstream senior water rights owners	4.0	4.0	2.3	3.6	3.7	1.8	3.1	3.7	4.9	3.2	1.8	3.4	3.0	24.3	20.3	14.8	6.4	0.0	65.7
4.01.041	Changes in types of beneficial use - irrigation, municipal, domestic, wildlife	4.0	3.3	2.8	3.4	3.2	3.5	2.8	3.3	4.7	2.8	3.0	3.7	2.9	23.7	22.2	13.2	5.7	0.0	64.6
4.01.003	Park use -- watercraft-use days by month & type of watercraft	2.4	3.5	3.0	3.5	3.0	3.0	4.0	2.8	4.0	3.3	2.4	1.2	2.8	21.7	23.3	11.3	6.7	0.0	63.0
4.01.015	Diseases -- frequency & extent of occurrence within surrounding region, by type	1.9	4.2	3.3	3.7	3.6	3.2	4.1	2.1	3.1	3.1	0.6	1.2	0.9	22.9	25.3	8.4	6.2	0.0	62.7
4.01.040	Changes in points of diversion for permitted water withdrawal	4.0	2.8	1.7	3.8	3.2	3.5	3.0	2.7	4.8	3.7	3.0	2.2	2.7	21.4	22.6	10.7	7.3	0.0	62.0

Table A-12 continued.

ID	Attribute or measure (candidate vital sign)	Evaluation Criteria (see Table A-9 in for explanation of individual criteria)													Total Weighted Scores (weight per category, in percent)					
		Management Significance				Ecological Significance			Feasibility / Cost		Response Variability	Existing Data / Programs								
		1.1	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**4.1**	**5.1**	**5.2**	**5.3**	**Mgmt. Signif. (35)**	**Ecol. Signif. (35)**	**Feas. & Cost (20)**	**Varia-bility (10)**	**Existing Data (0)**	**Total Score (100)**
Stressors																				
4.01.013	Feral animals within park -- distribution & abundance by type of animal	2.8	3.3	3.7	3.8	3.2	3.1	2.8	2.1	4.4	3.6	0.7	0.5	0.7	23.7	21.3	8.4	7.1	0.0	60.5
4.01.042	Changes in type of water right - diversion versus storage	4.0	3.3	1.9	3.4	3.3	2.0	2.5	3.4	4.4	2.3	3.0	3.4	2.8	22.0	18.3	13.7	4.7	0.0	58.7

Appendix B. Sample Measures Pertinent to Broadly Applicable Vital Signs

Prepared by:

Mark Miller, USGS-BRD

15 August 2003

Table B-1. Sample measures of vital signs that are broadly applicable across parks of the Northern Colorado Plateau Network. Narrowly applicable, park-specific vital signs (e.g., pertaining to particular at-risk species or unique ecosystems such as caves) are not included in this table. Table 5 and park-specific vital-signs tables (in main body of Phase II Report) indicate actual vital signs identified for each park. Measures used to monitor particular vital signs may vary both among and within individual parks depending on site- and scale-specific considerations.

Vital-sign category	**VITAL SIGNS**	**Sample measures** (measures vary in degree of specificity; those with potential applicability to multiple vital signs are indicated in **bold type**)
Ecosystem characteristics		
Climatic conditions	Precipitation patterns	**Total daily precipitation**
		Frequency, magnitude, and duration of precipitation events
		Form of precipitation (rain vs. snow)
	Air temperature patterns	Daily minimum and maximum air temperatures
	Wind patterns	Average wind velocity and direction
		Frequency, magnitude, duration, and directionality of wind events
Air quality	Atmospheric deposition	Nitrogen deposition
		Sulfur deposition
		Major cation & anion deposition
	Visibility	Atmospheric particulate concentrations
		Visual range
		Light extinction
		Deciview
	Tropospheric ozone levels	Atmospheric ozone concentrations
		Foliar characteristics of ozone-sensitive plants
		Physiological performance of ozone-sensitive plants

Table B-1 continued.

Vital-sign category	VITAL SIGNS	**Sample measures** (measures vary in degree of specificity; those with potential applicability to multiple vital signs are indicated in **bold type**)
Ecosystem characteristics		
Soil, water & nutrient dynamics	Upland soil / site stability	**Spatial distribution & density of social trails**
		Spatial distribution & density of trailing by large ungulates
		Spatial distribution & density of vehicular disturbances
		Spatial extent of soil disturbances associated with trailheads, campgrounds, and other high-use areas
		Number, spatial distribution, and spatial extent of backcountry campsites
		Cover of biological soil crusts by morphological group
		Cover and structure of live vegetation
		Soil aggregate stability (field index)
		Litter and rock cover
		Size of bare-ground patches
		Soil-surface height in relation to benchmark
		Soil accumulation behind silt fences or natural sediment traps
		Soil accumulation in dust traps
	Upland hydrologic function	**Soil penetration resistance (compaction measure)**
		Spatial distribution & density of social trails
		Spatial distribution & density of trailing by large ungulates
		Spatial distribution & density of vehicular disturbances
		Spatial extent of soil disturbances associated with trailheads, campgrounds, and other high-use areas
		Number, spatial distribution, and spatial extent of backcountry campsites
		Cover of biological soil crusts by morphological group
		Cover and structure of live vegetation
		Soil aggregate stability (field index)
		Litter and rock cover
		Size of bare-ground patches
		Soil-surface height in relation to benchmark
		Soil accumulation behind silt fences or natural sediment traps
	Nutrient cycling	**Cover of biological soil crusts by morphological group**
		Litter cover
		Size of bare-ground patches
		Cover of live vegetation
		Soil penetration resistance (compaction measure)
	Stream flow regime	**Continuous stream flow / discharge (cfs or cms); stream hydrograph characteristics (e.g., flow duration curves)**
		Number and duration of dry periods in streams and rivers
		Frequency and duration of flow in ephemeral and intermittent channels

Table B-1 continued.

Vital-sign category	VITAL SIGNS	**Sample measures** (measures vary in degree of specificity; those with potential applicability to multiple vital signs are indicated in **bold type**)
Ecosystem characteristics		
Soil, water & nutrient dynamics	Stream / wetland hydrologic function	**Areal extent of riparian / wetland vegetation**
		Composition, structure, and vigor of riparian / wetland plant communities
		Stream channel morphology – surveyed cross sections
		Spatial distribution and size of sediment deposits / sandy beaches along major rivers
		Stream sediment load
		Spatial distribution & density of social trails in riparian / wetland zones
		Spatial distribution & density of trailing by large ungulates in riparian / wetland zones
		Spatial distribution & density of vehicular disturbances in riparian / wetland zones
		Soil penetration resistance (compaction measure) in riparian / wetland zones
	Groundwater dynamics	Water quantity (flow / discharge) at seeps, springs, hanging gardens
		Areal extent of wet soil / substrate associated with seeps, springs, hanging gardens
		Water-table elevation in relation to ground-surface elevations along ephemeral stream reaches
		Groundwater depth in wells pertinent to park groundwater recharge (small, regional aquifers)
		Areal extent of groundwater-dependent vegetation
		Composition, structure, vigor of groundwater-dependent plant communities
Water quality	SEE WATER QUALITY SECTION	
Disturbance regimes	Fire regimes	Fire occurrence on park lands – frequency, spatial distribution / extent, intensity, and timing
		Fire management activities on park lands – spatial distribution and timing by type of activity
		Spatial distribution and relative proportion of park lands in different “fire regime current-condition classes”
		Spatial distribution / continuity and proportional cover of fine surface fuels (differentiated by native & exotic vegetation)
		Spatial distribution / continuity of fuel types
	Hillslope erosional processes	Changes in slope profile in relation to benchmark
		Rate of slope retreat in relation to benchmark
	Extreme climatic events	**Total daily precipitation**
		Frequency, magnitude, and duration of precipitation events
		Frequency, magnitude, duration, and directionality of wind events
		Continuous stream flow / discharge (cfs or cms); flow events described by magnitude, frequency, timing, duration, and rate of change
		Distribution / extent and abundance of standing dead trees in woodland / forest ecosystems

Table B-1 continued.

Vital-sign category		VITAL SIGNS	**Sample measures** (measures vary in degree of specificity; those with potential applicability to multiple vital signs are indicated in **bold type**)
Ecosystem characteristics			
Disturbance regimes		Extreme climatic events	**Distribution / extent and abundance of diseased / stressed trees in woodland / forest ecosystems**
		Insect / disease outbreaks in forests and woodlands	**Distribution / extent and abundance of standing dead trees in woodland / forest ecosystems**
			Distribution / extent and abundance of diseased / stressed trees in woodland / forest ecosystems
Biotic integrity	Predominant plant communities	Status of predominant upland plant communities (particular communities of interest may vary among parks in relation to values, threats, and probability / consequences of change)	**Composition and structure of predominant upland plant communities**
	At-risk species or communities	Status of at-risk species – amphibian populations	Proportion of area occupied (PAO)
			Frequency of malformations
		Status of at-risk species – bat populations	Trends in key population parameters (e.g., colony size)
		Status of at-risk species – Mexican spotted owl populations	Territory occupancy
			Productivity
		Status of at-risk species – peregrine falcon populations	Territory occupancy
			Productivity
		Status of at-risk species – other TES vertebrate populations (species vary by park)	Potential measures vary by species
		Status of at-risk species – TES plant populations (species vary by park)	Potential measures vary by species
		Status of at-risk communities – riparian-obligate birds	Abundance and diversity of riparian-obligate birds
		Status of at-risk communities – sagebrush-obligate birds	Abundance and diversity of sagebrush-obligate birds
		Status of at-risk communities – pinyon-juniper-obligate birds	Abundance and diversity of pinyon-juniper obligate birds
		Status of at-risk communities – native fish communities	Abundance and diversity of native fish communities

Table B-1 continued.

Vital-sign category		VITAL SIGNS	**Sample measures** (measures vary in degree of specificity; those with potential applicability to multiple vital signs are indicated in **bold type**)
Ecosystem characteristics			
Biotic integrity	At-risk species or communities	Status of at-risk communities – native grassland / meadow plant communities	**Composition and structure of grassland / meadow plant communities**
		Status of at-risk communities – sagebrush shrubland / shrubsteppe plant communities	**Composition and structure of sagebrush shrubland / shrubsteppe plant communities**
	At-risk species or communities / Focal species or communities	Status of at-risk / focal communities – riparian / wetland plant communities	**Composition, structure, and vigor of riparian / wetland plant communities**
			Areal extent of riparian / wetland vegetation
	Focal species or communities	Status of focal communities – biological soil crusts	**Composition and structure of biological soil crust communities (by morphological group)**
		Status of focal communities – aquatic macroinvertebrates	**Abundance and diversity of aquatic macroinvertebrates by functional group**
	Focal species or communities / Endemic species or unique communities	Status of focal / unique communities – spring, seep, & hanging-garden communities	**Areal extent of groundwater-dependent vegetation**
			Abundance and diversity of obligate taxa
	Endemic species or unique communities	Status of rare / endemic plant populations (species vary by park)	Potential measures may vary by species
		Status of other unique communities (communities vary by park)	Potential measures may vary by type of community
Landscape-level patterns		Land cover	Number, areal extent, and relative proportions of land-cover (ecosystem) types on park lands
			Spatial distribution and configuration of land-cover types on park lands
			Number, areal extent, and relative proportions of land-cover types on adjacent lands
			Spatial distribution and configuration of land-cover types on adjacent lands
		Land use	Number, areal extent, and relative proportions of land-use types on park lands
			Spatial distribution and configuration of land-use types on park lands
			Number, areal extent, and relative proportions of land-use types on adjacent lands
			Spatial distribution and configuration of land-use types on adjacent lands
		Land condition	Areal extent and relative proportions of park lands in different ecosystem-condition classes (defined by degree of departure from desired condition)
			Spatial distribution and configuration of ecosystem patches on park lands classified by ecosystem condition
			Areal extent and relative proportions of adjacent lands in different ecosystem-condition classes

Table B-1 continued.

Vital-sign category	VITAL SIGNS	**Sample measures** (measures vary in degree of specificity; those with potential applicability to multiple vital signs are indicated in **bold type**)
Ecosystem characteristics		
Landscape-level patterns	Land condition	Spatial distribution and configuration of ecosystem patches on adjacent lands classified by ecosystem condition
	Park insularization	Cross-boundary contrast between park lands and adjacent lands on basis of land cover, land use, and/or ecosystem condition
	Landscape fragmentation and connectivity	**Spatial distribution and configuration of land-cover types on park lands**
		Spatial distribution and configuration of land-cover types on adjacent lands
		Patch-size distribution of different land-cover types on park lands
		Patch-size distribution of different land-cover types on adjacent lands
		Movement / habitat-use patterns of large ungulates on park and adjacent lands
		Movement / habitat-use patterns of mountain lions on park and adjacent lands
Other vital-sign categories		
Stressors	Park use by visitors	Terrestrial visitor-use days by location, month, and type of activity
		Watercraft-use days by month and type of watercraft
		Park visitation by month (total no. of visitors)
		Frequency, location and nature of reported human-wildlife interactions
	Invasive exotic plants	Distribution and abundance of exotic plants by species
		Age- or size-class structure of exotic woody species
	Invasive, exotic, and/or feral animals	Distribution and abundance of feral animals
		Distribution and abundance of brown-headed cowbirds
		Distribution and abundance of exotic amphibians (e.g., bullfrogs)
		Distribution and abundance of exotic fish populations
		Distribution and abundance of exotic macroinvertebrate populations
	Occurrence patterns of novel diseases / pathogens	Frequency and extent of occurrence within surrounding region, by type (e.g., chronic wasting disease, West Nile virus)
	Permitted consumptive / extractive activities on park lands	Location, timing / duration, and intensity of permitted livestock use (e.g., AUMs)
		Location, type, and condition of livestock-related infrastructural developments
		Other permitted extractive uses – location, timing, and type of activity
	Park administration and operations	Location, timing, and type of weed-control activities
		Location, timing, and type of infrastructural maintenance activities (including roads and trails) by NPS and other permitted entitees
		Location, timing, and type of new infrastructural development by NPS and other permitted entitees
	Changes in stream hydrologic regimes due to surface-water diversions	Upstream and downstream density of water diversions
		Permitted water withdrawals from upstream and downstream water diversions (equate to flow reduction)
		Calls from downstream senior water rights owners

Table B-1 continued.

Vital-sign category	VITAL SIGNS	**Sample measures** (measures vary in degree of specificity; those with potential applicability to multiple vital signs are indicated in **bold type**)
Other vital-sign categories		
Stressors	Changes in stream hydrologic regimes due to surface-water diversions	Changes in type of water right (e.g., diversion vs. storage)
		Changes in points of diversion for permitted water withdrawals
		Changes in types of beneficial use (e.g., irrigation, municipal, domestic, wildlife)
		Small impoundments in watershed (no. of acres)
	Changes in stream hydrologic regimes due to large reservoirs	Downstream and upstream distance of dams
		Hydropower calls
		River regulation / reservoir operation
	Changes in groundwater hydrologic regimes due to groundwater extraction	Amount of groundwater extracted in watershed
	Adjacent / upstream land-use activities	Logging activities on adjacent lands (within park watershed) – location / extent, timing, and type of operation
		Livestock grazing activities on adjacent lands – location / extent, timing / duration, and intensity (e.g., AUMs)
		Spatial distribution and density of vehicular disturbances on adjacent lands
		Pesticide applications – frequency and timing of occurrence within park airsheds and watersheds by type and quantity of compound
		Geophysical / mineral exploration and development on adjacent lands – location / extent, timing and type of operation
	Non-compliant uses on park lands	Location, timing / duration, and intensity of unpermitted (trespass) livestock use
		Frequency and total no. of cases of resource theft, poaching, and/or vandalism
		Other non-compliant uses – frequency, location, timing / duration, and type of activity
Other natural resource values	Status of paleontological resources	Spatial distribution and density of social trails in relation to exposures of fossil-bearing substrates
		Spatial distribution and density of vehicular disturbances in relation to exposures of fossil-bearing substrates
		Relative condition of individual fossil-resource sites, defined on basis of natural and anthropogenic risk factors
		Rates of fossil loss and exposure by erosion on fossil-bearing substrates
	Status of natural night skies	Night sky brightness
	Status of natural soundscapes	Sound levels (in dB) by frequency
		Sound sources (recorded audibility data)

Appendix C. Summary of Water Quality and Quantity Vital-Signs Workshop

Prepared by:

Dave Sharrow, NPS Zion National Park
Lynn Cudlip, Western State College

17 September 2003

On April 11 and 12, 2003, twenty-three people met in Moab to select proposed water quality and quantity vital signs for the Northern Colorado Plateau Network (NCPN). The purpose of the workshop was to identify high priority waters for monitoring, likely sample sites, parameters to be sampled, suggested sampling schedules and logistical considerations for each of the 16 network parks, which will constitute the draft water quality vital signs. It is recognized that these may be modified as the sampling design proceeds in Phase III.

The summary in this appendix is primarily limited to the discussions that took place at the workshop. A full presentation of the vital sign selection process was presented in Appendix A and in the body of the Phase II report. Workshop participants are listed in Table C-1 at the end of this appendix.

APPROACH

As mentioned in the servicewide guidance for development of water quality vital signs (NPS-WRD 2001) there can be several approaches to vital sign selection including a Delphi process (an iterative planning process) and collaborative Internet brainstorming. The Northern Colorado Plateau Network used an approach which meshed perceived management issues as identified by park managers, with preliminary analyses of water quality data undertaken by the U.S. Geological Survey, in addition to the Internet brainstorming effort. Early efforts as part of Phase I focused on the identification of management and scientific issues, which were presented in Appendices O and P in the NCPN Phase I Report (Evenden et al. 2002).

The basis for this approach stems from several sources including Kunkle and colleagues (1987), MacDonald (1991), Davis and colleagues (2001), and online guidance provided by the U.S. Environmental Protection Agency (EPA) at www.epa.gov/owow/monitoring/elements/elements.html#6. Some of the materials from these sources that have been useful are included in this appendix. The EPA website recommends water quality indicators for general designated use categories as shown in Table C-2 at the end of this appendix. Use category refers to the type of use that a particular water body or stream reach supports. Each state assigns designated use categories and develops quantitative and qualitative standards to protect these uses. In Table C-3, Kunkle and colleagues (1987) suggest another valuable approach, where parameters are linked to specific threats. Differences between protected uses or park management concerns and the type of water source (e.g. large rivers versus springs) is depicted in Table C-4.

The selection of water quality vital signs by the group was a first attempt at identifying parameters that can aid managers in their efforts to recognize water quality and quantity degradation. By working within state water quality standards it should be possible to select a suite of parameters that can lead to quantitative management triggers or thresholds in relation to indicator values. In addition, a park interested in obtaining an Outstanding Natural Resource Water designation for their waters can undertake monitoring with emphasis placed on documenting existing water quality.

Actions Preceding Workshop

The following actions took place prior to the workshop, provided a basis for the discussions that occurred, and made it possible to select draft vital signs for the 16 NCPN park units in a very limited 2-day workshop:

- Developed a servicewide Program Guidance draft document (NPS Water Resources Division),
- Developed a Baseline Water Quality Inventory and Analysis horizon draft document (NPS Water Resources Division, a compilation of data in the STORET database, and limited analysis),
- Analyzed and distributed a questionnaire soliciting input from park staff regarding their significant waters and water quality issues (Colorado State University).
- Conducted park visits to discuss water quality concerns and review available literature (Colorado State University),
- Established contacts with managers of adjacent lands and state water quality agencies (Colorado State University),
- Identified all waters in NCPN parks that are included on the state's 303d lists of waters not meeting standards (Colorado State University),
- Conducted a scoping workshop for NCPN parks in June 2002 that established priorities and goals for water quality monitoring (NCPN),
- Identified water quality issues in each park (NCPN, see Appendices O and P in the NCPN Phase I report),
- Included water quality vital signs in the Delphi process used to develop broader natural resource vital signs (NCPN),
- Assembled available data from STORET, legacy STORET and NWIS, and developed a relational water-quality database conducive to analysis (U.S. Geological Survey, Water Resources Discipline; USGS-WRD),
- Conducted preliminary analyses of data for areas of concern and exceedences of state standards (USGS-WRD); (This was done both prior to the workshop and with real-time data analysis during the workshop),
- Conducted a Water Quality Vital Signs Workshop in April 2003, and
- Provided Workshop participants with numeric and graphical data summaries for each park.

Vital Signs Selection in Relation to Park, Network and Servicewide Goals

In a NCPN water quality workshop held in June 2003, participants agreed that legal mandates, e.g. the Clean Water Act, were the most important to address in the selection of vital signs and a monitoring effort. There was also interest in focusing on long-term monitoring needs as opposed to short-term management needs. The group agreed that the overall NCPN network goals for water-quality and quantity are:

1. Collect, analyze and interpret data to support management in relation to 303(d) listings of waters,
2. Collect, analyze and interpret data to support management of threatened or otherwise special waters, using state standards developed under the Clean Water Act, and
3. Identify data needs, including inventory requirements, in relation to the status and trends of selected indicators for the condition of park ecosystems. These data can provide early warning signs to provide resource managers with the ability to mitigate problems and improve park resources.

Consistent with NPS-WRD recommendations, these goals are ordered to acknowledge that legal mandates are clearly the first priority.

WORKSHOP DISCUSSION

Northern Colorado Plateau Network Perspective

Paul von Guerard, UGSG Grand Junction, presented several general water quality and quantity issues from a network perspective and based on management issues presented by the parks. These include: 1) human contact, 2) recreational impacts, 3) effects of pending and ongoing development adjacent and internal to parks, 4) livestock grazing, 5) threatened and endangered fish and other aquatic species, 6) in-stream water quality standards determined under the Clean Water Act, and 7) land use effects on adjacent federal or state land. He offered Table C-3 (from Kunkle et al. 1987) which depicts key parameters that may respond to each category of impact.

Another means of assessing the parks at a network level derives from the types of water sources within the parks. Two major categories are surface waters and ground waters. Within surface waters, the NCPN parks have examples of perennial, intermittent and ephemeral (e.g. tinajas) water sources. The parks also support groundwater discharges, such as seeps, hanging gardens and springs, which may be included as surface waters. Table C-4, also offered by Paul von Guerard, depicts a matrix of the association between parks, their hydrological characteristics and water quality and quantity issues.

Of major concern to several parks is adjacent land development with increased water consumption and wastewater discharge. Mining of groundwater outside park boundaries may reduce water yield from springs, seeps and wells that support park drinking water sources and wildlife habitat.

Water-Quality and Quantity Issues of Special Interest to Several NCPN Parks

Selenium is a contaminant throughout much of the Colorado River basin with elevated levels due to irrigation practices and development (Butler and Lieb, 2002). Natural background levels are high and associated with particular soil types and geological features such as Mancos shale. Discussions in the workshop concluded that monitoring of selenium would be adequately addressed by (1) including selenium in trace element analysis for the Colorado River and major tributaries, and (2) further studies by the USGS and others agencies.

Pesticides can also be problematic along major rivers in some of the network parks such as Dinosaur NM and Canyonlands NP. While valid, this concern will have to be addressed outside of the NCPN monitoring program due to the very high cost of laboratory analysis for pesticides. Special studies for these parameters may be warranted.

Common water features in NCPN parks are springs, seeps, and tinajas. These sources of water are critical to flora and fauna, and aesthetically important to park visitors and staff. Monitoring is sometimes difficult because the individual water sources, though often diminutive, can be numerous and can have diffuse points of discharge that are difficult to sample. A network approach applicable to many springs is to rotate sampling from year-to-year among several springs, as is currently done in the Southeast Utah Group of parks. In addition, a NCPN effort to specifically inventory and monitor seeps and springs is planned and will be prefaced by a design of a program for the network. Though this will have a broader focus than just water quality and quantity, it will also include an attempt to measure flow, and will likely include site visits that present an opportunity to collect water quality samples.

Existing Monitoring

Two groups of parks have established monitoring efforts, the Southeast Utah Group of parks and a joint effort in Black Canyon of the Gunnison NP and Curecanti NRA. The Southeast Utah Group has been monitoring its water quality and quantity since the early 1990s. Black Canyon of the Gunnison NP/Curecanti NRA is monitoring their waters in an effort to attain anti-degradation and Outstanding National Resource Water status for approximately 21 water sources. These existing monitoring programs provide examples that can be applied to other parks.

Relating Vitals Signs Selection to Ecological Models

Several parks including Black Canyon of the Gunnison NP, Curecanti NRA, Capitol Reef NP, Canyonlands NP, Dinosaur NM, and Zion NP have large river systems flowing through them. These are major drivers affecting both the physical and biological components of the parks' ecosystems. As noted in the discussion of the ecological model for riverine systems in the Phase I report, understanding the importance of the spatial and temporal scale leads to development of a monitoring program which may detect system degradation over the long-term via measurement of sediment transport and channel morphometry. Monitoring for the long-term was of particular interest to the June 2002 workshop participants. However, a more immediate concern is capturing water quality characteristics that can change rapidly (e.g. minutes, hours or daily fluctuations) such as streamflow, temperature, pH, dissolved oxygen and specific conductance. Several years of data, and/or data collected at frequent intervals, are needed to reveal trends that relate to system degradation. Since measuring sediment transport is expensive and difficult, biological monitoring may serve as a link between monitoring water quality and trying to determine if the system has degraded to a point that the major ecosystem drivers have changed. Figure C-1 (from Davis et al. 2001) integrates aspects of river ecosystems, emphasizing the importance of the biological component.

Core Vital Signs

The NPS Water Resources Division has added flow to the original core vitals signs for water quality (pH, temperature, specific conductance, and dissolved oxygen). The participants concurred with this decision, citing the intimate relationship between flow and the concentration of many dissolved constituents, between flow and sediment transport, and the need to consider flow in effective data analysis. If flow could not be measured quantitatively, then, at a minimum, a qualitative measurement such as low, medium, or high would be assigned. Several workshop participants mentioned the importance of water quantity from its potential as floods flowing in small canyons in Colorado NM, to its ability to carry sediments in the Green, Yampa, Colorado, and Fremont rivers.

Park-by-Park Selection of Vital Signs and Sites

The participants proceeded with a park-by-park selection of vital signs. The following is a summary of the discussions that took place. Matrices depicting water sources, vital signs, schedules, priorities and logistical considerations were developed for each park. These can be found in the body of the NCPN Phase II report, so are not included in this appendix. [For ease of use, park discussions are presented below in alphabetical order rather than in the chronological order as they occurred during the workshop.]

<u>Arches National Park, Canyonlands National Park, Hovenweep National Monument, and National Bridges National Monument (Southeast Utah Group)</u>

Charlie Schelz provided an overview of water resources and threats to the four parks. Cooperative monitoring with the Utah DEQ currently occurs. The park samples monthly at several sites (typically three) and rotates through sites each year over a 3-year period. The park program costs from $5000 to $10,000 per year. Utah DEQ's contribution is the analysis of samples and data entry. Analysis costs $350/sample.

Paul von Guerard wondered if there is a concern whether the current QA/QC documentation is sufficient to meet legal scrutiny, as QA/QC data scrutiny is becoming a major issue. Pete noted that QA/QC is addressed in the NPS-WRD guidance for WQ monitoring. The Phase III report will address water quality design work and will have to include QA/QC protocols.

At Arches NP, Courthouse Wash, Freshwater Spring, Sleepy Hollow (the pool), Willow Spring, and Salt Wash are currently monitored for core parameters, flow, nutrients, major ions, trace elements, total suspended solids and dissolved solids 12 times/year. Sites are rotated annually such that 3 sites per year are monitored. Macroinvertebrates are monitored on a quarterly basis, and microorganisms on a monthly basis in-house.

At Hovenweep NM, the park monitors Little Ruin, Hackberry and Cahon springs. At Natural Bridges NM, the park monitors Tuwa, White and Armstrong springs. The same suites of parameters that are measured at Arches NP are also measured at Hovenweep NM and Natural Bridges NM. At Canyonlands NP, the Green and Colorado Rivers are monitored from April through October on a monthly basis. The Utah DEQ appreciates this effort since accessibility is difficult. The park monitors core parameters, flow, nutrients, trace elements, major ions, total suspended solids, dissolved solids and turbidity. They would also like to monitor pesticides. Also in Canyonlands NP, Cave Spring, Little Spring Canyon, 2.4 Mile Loop, Bates-Wilson, Crescent Arch, Peekaboo, and the Maze Overlook are monitored for the same parameters as springs in Arches NP. The SEUG would like to continue with this monitoring effort that they began in the late 1980s, and would like support for the program. SEUG considers all of their sites high priority, with the rotating scheme working well.

Bryce Canyon National Monument

Sharrow provided a description of park geology and hydrology. The park and its developed areas sit atop the rim of the Paunsaugunt Plateau. Many of the springs are downslope from this.

Kelly Cahill provided an overview of park issues and noted that the Tropic ditch, a privately owned water conveyance that flows through the park, serves as a vector for weed introduction. This unlined ditch provides a major source of irrigation water for farmers in Tropic, and could possibly be recharging springs in that area of the park. Other issues for the park include livestock trailing through meadows and potential development on BLM land south of park managed by Kanab Field Office. The potential issue associated with coal bed methane is the discharge of large amounts of wastewater that might potentially contaminate the Navajo sandstone aquifer. The park is concerned, since it may eventually need to drill into the Navajo to acquire water for park uses. Wastewater disposal within the park occurs on the rim and could potentially impact spring water quality; however the infrastructure has been newly lined and working well.

Incidence of chitrid fungus on amphibians occurs in the Dixie NF below Bryce Canyon NP. Kevin Alexander noted that there is probably not a water quality link associated with this fungus.

The group agreed that Yellow and Sheep creeks were a high priority and could be monitored cooperatively. Core parameters, flow, nutrients, major ions, total dissolved solids, turbidity, and macroinvertebrates would be measured. Other springs (Cope, Water Canyon, Campbell, Right Fork, Iron, Lonely and Riggs springs) below the rim were considered as high priority with the same parameters measured as for the creeks. The group agreed that the Podunk Creek wetland was of medium priority and could be rotated with the other springs. Dave's Hollow was low priority since the park could rely on water supply monitoring at this site.

Capitol Reef National Park

Tom Clark presented a synopsis of the park waters and issues. He noted a need for baseline data for the park's tinajas, a very important water feature for the park. This effort could be a part of the entire spring/seep inventory being contemplated by the network.

The Fremont River is on the 303(d) list. Although the river is viewed as one segment from its headwaters to the eastern boundary of the park for state water quality standards, the 303(d) listing separates it into 2 segments for water quality limitations. From Bicknell (which is west of the park) to its headwaters, the Fremont is listed as not meeting standards for dissolved oxygen and total phosphorus. From its confluence with Muddy Creek to the park's eastern boundary, the Fremont River is listed for total dissolved solids. In essence, the Fremont River within the park is not on the 303(d) list, though total phosphorus levels at Hickman Bridge (within the park) have exceeded the state guidelines for total phosphorus on several occasions. The TMDL is complete for the river and various best management practices, such as removal of a corral adjacent to the river, are being applied. Tom Clark suggested waiting to see if these practices improve the turbidity and total phosphorus levels within the park.

The park would like to monitor the Fremont River, and the perennial Sulphur, Pleasant, Oak, and Halls creeks. They would also like to monitor the intermittent Deep, Polk and Bulberry creeks. The highest priority would be given to the perennial creeks, while the state would continue to monitor the Fremont River. The park would cooperatively sample the other creeks. A suite of information would be monitored including core parameters, flow, nutrients, trace elements, and major ions, total suspended solids and dissolved solids. Due to access difficulty, Capitol Reef NP could perhaps coordinate with GLCA or another park to sample Halls Creek. Deep, Polk and Bulberry creeks, and Middle Desert Wash received medium priority with measuring of core parameters, flow, and macroinvertebrates.

Cedar Breaks National Monument

Sharrow provided an overview of park geology, water resources, and issues. Water quality issues are minor at Cedar Breaks NM, since park development does not impact springs. The park is situated in a high elevation position on the Colorado Plateau at the watershed divide between the Sevier River to the east and Coal Creek to the west. It could serve as a useful baseline measurement site for springs representative of the general geologic area. The issues that are most important include the park's wastewater treatment system, trespass cattle grazing and grazing near springs, particularly the spring that supports the Arizona willow (Salix arizonica). Pesticide use to control beetles on adjacent National Forest lands is another concern.

Cedar Breaks has springs within the breaks (the very rugged area of the park below the rim) and a few on the rim. Blowhard Spring is the drinking water source for the park and is monitored by the park. Sampling Alpine Pond, and the springs on the rim is a low priority and could be easily rotated in a 2-year program with Zion NP. The springs located in the breaks are of medium priority and could be part of the network spring and seep inventory with a comprehensive water quality analysis including core parameters, flow, nutrients, major ions, trace elements, total suspended solids and dissolved solids. Routine monitoring of springs in the breaks would present significant logistical problems.

Colorado National Monument

The monument lies on the northeastern edge of the Uncompahgre Plateau where it abruptly terminates and joins the Grand Valley. The park encompasses geologic features consisting of very steep drainages cutting through shales and sandstones of the Jurassic age. The Wingate Formation is the most visible geologic layer. Above the park is the Glade Park area, where development of 35-acre and smaller tracts occurs. The major issue at Colorado NM is water quantity. Water can flow through steep canyons downstream into an area where houses have been built at the mouth of the canyons on alluvial fans and in floodplains. A flood in No Thoroughfare Canyon was estimated by park staff to be 9000 cfs. Water in canyons from springs does not ordinarily reach the Colorado River, though flow from storm events can easily reach the mouths of the canyons and any dwellings in their floodplain.

A synoptic water quality study was conducted by USGS for all of the drainages within the park. Selenium levels in some drainages were above state standards; however, this most likely is a result of natural background levels. More importantly, the park could measure flows in canyons that would be covered under the inventory and monitoring effort. Water quantity measurements are a particularly high priority in No Thoroughfare Canyon, Monument Canyon, Fruita Canyon, and Red Canyon. These sites would be monitored once per month and also during spring runoff and during large precipitation events.

Curecanti National Recreation Area and Black Canyon of the Gunnison River National Park

Matt Malick provided an overview of the parks and their water issues. Threat of future water degradation is primarily from housing/urban/resort development in canyons and along drainages.

Curecanti NRA/Black Canyon of the Gunnison NP changed their water quality monitoring program a couple of years ago to begin intensive sampling aimed at attaining Outstanding National Resource Water (ONRW) status for some of their waters. Malick and his crew sample 21 sites in both parks. Almost all sites reveal good water quality adequate for anti-degradation designation, but it is currently, and will continue to be, a political issue. Most anti-degradation designations in the State of Colorado are on wilderness streams, which are at high-elevations in upper basins where no upstream uses could be impacted by such a designation. Anti-degradation standards are specific to particular parameters. If the designation were attained, the park would probably require compliance sampling at least quarterly. Current sampling is 7 times per year.

Funding to support data acquisition in support of anti-degradation designation runs through the end of 2004, but the park needs data through 2006 to build the required data record for the state rulemaking.

The parks would like to begin monitoring volatile organic carbon (VOCs) to assess the contamination of reservoir waters by fuels from motorboats and other motorized water craft, thought it was noted that VOCs are very expensive to monitor. Synoptic sampling efforts are almost prohibitively expensive.

Sharrow questioned Malick about his concern with the susceptibility of Curecanti NRA/Black Canyon of the Gunnison NP waters to effects of atmospheric deposition due to low ANC / alkalinity (acid), or atmospheric deposition of toxics / metals (e.g., mercury). As this time, there does not appear to be a concern. Kirby Wynn noted that the USGS has an atmospheric deposition network in the Rocky Mountains and throughout the west in cooperation with the NPS and other agencies. To detect mercury deposition, one has to sample the snow pack, which is very difficult to adequately do. Another method is to sample fish tissues. Kirby Wynn will work with Dave Sharrow and the NCPN to discuss data sources /issues regarding atmospheric deposition.

Consensus among the group was that the way to address monitoring for atmospheric deposition of metals, particularly mercury, was to use direct atmospheric deposition monitoring (e.g., NADP) rather than to monitor surface water chemistry. This discussion pertained to vital signs discussions earlier in the week. The surface water chemistry related to an atmospheric deposition vital sign was dropped and relegated to the water quality workshop discussions.

Malick had concern with potential high total P values in tributaries. Paul von Guerard suggested that this might be originating from volcanic geology. The USGS real-time display of data indicated that high total P is very common in the Curecanti NRA region.

The park's current sampling scheme was noted and documented in the accompanying matrix. The park samples the Gunnison, the Lake Fork of the Gunnison, and Cimarron rivers, and major tributaries and reservoirs for an array of parameters. They work with the USGS to accomplish the task.

Dinosaur National Monument

Tamara Naumann provided an orientation to Dinosaur NM and noted that it spans two states and serves as grazing land for approximately 2,300 AUMs of livestock with 11 separate allotments. The park is responsible for permitting livestock, yet has relatively no staff to administer the permits. The Green and Yampa rivers comprise the largest and most significant water sources in the park. Both Vermillion and Red creeks are significant tributaries to the Green River. These creeks contribute a substantial sediment load to the Green River, helping to recover the natural load lost as a result of Flaming Gorge Reservoir.

Naumann noted that her main concern with the Yampa is that it is the last major unregulated tributary in Colorado River system and stressed that the park needs good baseline monitoring for purposes of comparisons with regulated rivers. While there are diversions and depletions on the Yampa River, there are no big dams that prevent natural spring peak flows or summer low flows. Naumann suggested that the Yampa River should be considered as a reference area for the upper Green River, which is a regulated system.

Naumann wanted to add Cub Creek and Jones Hole Creek, the site of a fish hatchery, to the discussion matrix for consideration for monitoring. The discharge from the hatchery is sampled as part of the National Pollutant Discharge Elimination System (NPDES) program, but the park would like to take in stream samples as well.

Norm Henderson questioned if an NPS goal was to establish anti-degradation standards for the Yampa River. At the present time, it was not clear, though several participants noted that river rafters take precautions regarding infections from cuts and abrasions exposed to Yampa River water. As such, understanding supposed contamination of water by pathogens and its general quality might precede establishing anti-degradation standards.

Naumann wanted to ensure that Mark Vinson's macroinvertebrate data are in the USGS-NCPN database. One of the park issues is the appearance of the exotic New Zealand mud snail now in Green River below Flaming Gorge dam.

Some parameters are captured by other monitoring programs such as the U.S. Fish & Wildlife's efforts with temperature and pH at various sites on the Green and Yampa rivers (1987 – present, see www.rb.fws.gov/riverdata/.) Salinity was monitored on the Yampa River but was stopped due to a lack of data analysis. Paul von Guerard discussed questions associated with pH values in the Yampa River noting that recent analysis indicated that previously reported upward trends in pH may be attributable to poor methods and instruments through the mid-1980s (see Chafin 2002).

Naumann wanted to ensure that the spring/seep inventory design included input from water quality experts. Two water quality studies of the approximately 90 springs in the park have been completed (Rice 1998, Foster et al. 2000).

During a real-time data analysis by the USGS, Cudlip expressed concern with the total phosphorus data for the Green River in Dinosaur NM. Von Guerard suggested that total phosphorus should be plotted against TDS or TSS, which would reveal if the total phosphorus were associated with particulate matter. Richard Denton said the DEQ has not placed the Green River on the 303(d) list for total P, since it was fairly clear that the total P comes from the Yampa River, which is a state of Colorado problem. Colorado does not have a guideline or standard for total P.

The group agreed that the Green River would be monitored at the Gates of Lodore, and at the Jensen site where it is currently being sampled by the state of Utah. The Yampa River would be monitored at Deer Lodge. All of these are high priority sites. Parameters of interest included the suite that the Utah DEQ can collect and analyze, turbidity, total suspended solids, dissolved solids, and macroinvertebrates. Pesticides would be measured on the Yampa River since intense agricultural use occurs upstream. Of medium priority are Cub and Jones Hole creeks. The upland sites were considered low priority and should be studied as part of the network spring/seep inventory effort.

Fossil Butte National Monument

Clay Kyte would like to see watershed and sediment yield monitoring on Chicken Creek where flow is channeled into a culvert at the southern park boundary. The park has questions and issues related to previous livestock and railroad impacts. Von Guerard and Sharrow stated that the use of geomorphic indicators and aerial photos may be the best approach to look at watershed changes over time. The BLM wants to conduct a controlled burn on west side of the park using a park road within the park as a firebreak. Livestock were excluded from the park following the growing season of 1989. Fossil Butte NM supports one of the few ungrazed sagebrush systems in the region.

Kyte explained that the spring and seep zone occurs at the contact between the relatively coarse Green River Formation and the fine-textured Wasatch Formation. The springs feed approximately 20 ponds dammed by beavers, though most of these are currently dry due to drought. Kyte asked whether atmospheric deposition would manifest in springs since drawdown of recharge in the Green River Formation appears to be relatively rapid, within 2-3 years. The park also has a concern over the potential demand to develop water and pipe it outside of the park to support livestock.

The group suggested that the use of aerial photos and the park cross-section data would allow an evaluation of the Chicken Creek restoration efforts. The group also suggested looking at the plant community as a measure of recovery. Measurement of quantity would also be helpful.

Kyte noted that the NPS Horizon report for Fossil Butte NM did not adequately characterize the springs coming out of Green River Formation. The group decided that Cundick Spring, East and West Small Pox Springs, and the Green River Formation Springs were of medium priority and could be monitored 4 times per year. This effort would be coordinated with the overall network spring inventory. Chicken Creek was also of medium priority and would be monitored 4 times per year. However, the group thought that water quality assessment should be aligned with the aquatic and wetland and geomorphic indicator assessment.

Golden Spike National Historic Site

Dave Sharrow noted that park management considers it a low priority to monitor Blue Creek.

Richard Denton, with the Utah DEQ, has a site on Blue Creek below the Thiokol plant, which is within 200-300 yards of Golden Spike NHS. The USGS confirmed that data are in the NCPN-USGS database, though this single physical site has four different site IDs. The group concurred that Golden Spike NHS is covered sufficiently by the DEQ Blue Creek sampling. Blue Creek is characterized so that the state can discern what Thiokol is contributing to stream. At this time, Utah DEQ has not observed water quality problems on Blue Creek. Utah DEQ will work with NCPN/USGS to clarify the site IDs on Blue Creek. In general, each park should work with Utah DEQ to determine which sites contain possible multiple site names.

Pipe Spring National Monument

Issues are entirely water quantity related at Pipe Spring NM. Sharrow described the hydrogeology of the springs at the monument. Flow monitoring since the 1930's documents permanent flow from four springs. West Cabin Spring (mostly a seep) generally flowed from ½ to 2 gpm, Tunnel Spring (established in 1906 by digging a horizontal tunnel into the hillside) from 5 to 15 gpm, Main Spring from 5 to 30 gpm, and Spring Room Spring from 1-6 gpm. Flows from Main Spring and Spring Room Spring gradually diminished over the latter 1970's through the 1990's, while Tunnel Spring showed a slight increase in flow – suggesting that new fractures opened permitting water to flow by gravity to Tunnel Spring which is 20 feet lower in elevation.

In June, 1999, Main Spring and Spring Room Spring ceased to flow. To keep what water they had, and aware that the adit for Tunnel Spring was in poor condition, the monument attempted to stabilize the structure. A concrete tunnel was installed in an excavated trench to support the front ½ of the tunnel, but as stabilization proceeded deeper into the tunnel it collapsed completely. Discharge from Tunnel Spring was maintained by forcing culverts through the breakdown. It now discharges about 10 gpm. Water is now piped from Tunnel Spring to the Spring Room and ponds. Discharges from West Cabin Spring remain unchanged or have increased slightly during this period. It remains the only free flowing spring in the monument.

Water is pumped off site to meet a 1933 agreement to provide water for livestock growers and the Kaibab Paiute Indian reservation. The water is distributed as follows: 1/3 to NPS, 1/3 to the Kaibab Band of Paiute Indians, and 1/3 to the livestock users association. The park uses the tribal portion in exchange for potable water from the NPS well.

Since 1976, the NPS has observed a decline of about 50 percent in the combined discharge from springs at the monument, with an average decrease of about 2 (gal/min)/yr (Truini, 1999; Barrett and Williams, 1986). After discharge from Spring Room and Main Springs ceased in June 1999, Sharrow (1999) tested the addition and removal of water from Main Spring and Spring Room Spring, demonstrating that these features are hydrologically connected in the subsurface.

The group agreed that monitoring should occur at Tunnel Spring and West Cabin Spring. Water quality would be measured including core parameters, stream flow and major ions. The latter would be measured to continue to establish whether the springs are hydrologically connected. The monument recognizes that there could be serious water quality issues with these springs, though they are not used for drinking water. The monument supply is well upstream and may impact flow. The group suggested monitoring of springs on a quarterly basis as a medium priority. The group concurred that if the State of Utah lab were used, a suite parameters would be measured including nutrients and metals.

Timpanogos Cave National Monument

A fish advisory exists on the North Fork of the American Fork River. Recreational fishing does occur in the park. The advisory, from the Utah DEQ and the Utah Dept. of Health, notes that as a result of elevated arsenic levels in the fish meat, adults should limit their consumption of brown and cutthroat trout to no more than one meal per month. Pregnant women, nursing mothers and children under the age of 12 should avoid eating any trout from the creek (Utah DEQ, May 21, 2002 release on website). Because the Forest Service extensively monitors the American Fork River, a NPS effort would be of low priority.

The monument supports 3 major cave ponds and approximately 30 other pools. The greatest concerns are the cave waters. The monument received money to monitor caves for next 2 years (NPS-WRD project funding). Major ions and trace elements are of most interest. The group suggested waiting until the completion of this study to determine what will continue to be monitored.

There is a pit privy on the trail up to caves. A concern is that a potential source of contamination occurs from the privy to springs downstream. The park could fix the privy system, alleviating the need to monitor springs, however, the group conceded that monitoring for human waste or caffeine combined with the core parameters would be desirable if monitoring is to be performed.

Zion National Park

Dave Sharrow began the discussion by describing the park's waters, watershed land uses (agriculture/grazing, housing development, roads), and visitation patterns as they pertain to water resources. The main drainages include the East Fork of the Virgin River and the North Fork of the Virgin River. Other important perennial tributaries include North, La Verkin, Deep, Kolob, and Pine Creeks. Extremely important features of Zion NP are its hanging gardens and springs.

North Creek is on 303d list for total dissolved solids (TDS), however, the data is currently under state review. In addition, the source of the TDS is almost certainly natural discharge from springs in the park, so corrective action would not be desirable from the park's perspective.

Ninety percent of the stream flow in Zion NP is from groundwater discharge associated with the contact between the Navajo sandstone and the Kayenta formation. High visitor use occurs in the North Fork of Virgin River in the Narrows section where some 2000 visitors hike the canyon per day. Coal bed methane leases exist in North Fork drainage, but no development has occurred yet. Data review show high bacteria (fecal-coliform) results in North Fork of Virgin, probably attributable to upstream livestock / irrigated pastures on river banks above the park.

Richard Denton with the Utah DEQ noted that the BLM, in a cooperative manner with the State of Utah, is conducting regular sampling above the falls of La Verkin creek, which is 5 miles below Zion NP. As sampling was initiated approximately one year ago, data may not yet be uploaded to STORET and therefore, not captured in the USGS-NCPN database.

Sharrow's concern is that sampling frequency requirements for documenting bacteria exceedence are much higher than frequency requirements for chemistry exceedences. He recommended that bacteria be monitored synoptically to understand the system, rather than as part of a regular monitoring program because the high-frequency requirement would constrain a budget.

Denton recommended sending the macroinvertebrate samples to the Bug Lab in Logan, UT for analysis, since that is where the Utah DEQ sends their samples. He recommended spring-fall sampling, when most invertebrates are present. Kevin Alexander, Western State College, aquatic invertebrate specialist, concurred.

Charlie Schelz uses portable weirs for estimating discharge at hanging gardens in Arches NP and suggested a similar application for monitoring in Zion NP. Richard Denton was willing to analyze a few synoptic samples from hanging gardens or seeps in order to establish baseline conditions.

Tamara Naumann wondered whether it was premature to begin considering what parameters to monitor at hanging gardens before the NCPN seep/spring/hanging-garden inventory has been conducted, noting that baseline data can inform monitoring decisions. She was optimistic that the inventory would be designed with input from hydrologists who could recommend what hydrologic and water quality parameters should be included in the inventory. Schelz agreed. There was general support for the idea that monitoring of most springs, seeps and hanging gardens at any of the NCPN parks wait until the inventory has been completed.

Pete Penoyer remarked that the water quality-monitoring program is adaptive and can adjust in the future based on new data and/or considerations.

Paul von Guerard noted that caffeine has been used as an indicator of groundwater contamination by wastewater.

Norm Henderson questioned what the NCPN perspective was on the overall focus of vital signs monitoring - to track general trends in resources or to provide focused data for managers? He stated that while data collection is a fine endeavor, would that data be useful in allowing resource managers to find solutions to water quality problems?

Vital signs and potential sites for Zion NP were selected and priorities and schedules were noted (see discussion in body of Phase II report). The North and East Forks of the Virgin River will be monitored for the core parameters, nutrients, trace elements, major ions, macroinvertebrates, total dissolved solids, suspended solids and turbidity. The North Fork will additionally be monitored for microorganisms. The state can cooperate on several sites including the North and East Forks of the Virgin River. They will be working on North Creek as part of the TMDL analysis. The group concurred that Deep and Kolob Creeks were low priorities due to their remote location, and Pine Creek due to its minimal flow.

Other Topics Discussed

<u>Hypothesis Testing</u>

The NPS Inventory and Monitoring Program and the NPCN consider the formulation of monitoring questions as true hypotheses to be desirable. However in contemplating the process used to select vital signs, specific questions or hypotheses were not posed due to time constraints and the existing framework of water quality standards. Instead, management and scientific issues for each park were identified and the existing data analyzed. Specific hypotheses can be derived from both issues discussions and data analysis. For example, one of Arches NP's management concerns is stated as change in stream flow at springs from development. The question this park is posing becomes, "Development in the form of domestic wells changes flow at the park's spring." For Bryce Canyon NP one of the management concerns is the impact of visitor use in drainages and at springs. Translated into a hypothesis to be tested, this becomes, "Visitors impact the water quality of drainages and springs." More thoroughly, "Visitor activities increase turbidity, sedimentation or fecal coliform levels in the drainages." And statistically, this could be stated as, "Do 95% of all observations of turbidity fall within historic levels?"

LITERATURE CITED

Barett, D.C. and O.R. Williams. 1986. An Evaluation of the Decline in Spring Flow at Pipe Spring National Monument. Fort Collins, Colorado, National Park Service Report, 13 p.

Butler, David L. and K. J. Lieb. 2002. Characterization of Selenium in the Lower Gunnison River Basin, Colorado, 1988 – 2000. U.S. Geological Survey, Water Resources Investigations Report 02-4151, Denver, Colorado.

Chafin, Daniel T. 2002. Evaluation of Trends in pH in the Yamps River, Northwestern Colorado, 1950-2000. U.S. Geological Survey, Water Resources Investigations Report 02-4038, Denver, Colorado.

Davis, J. C., G. W. Minshall, C. T. Robinson, P. Landres. 2001. Monitoring wilderness stream ecosystems. General Technical Report RMRS-GTR-70. Rocky Mountain Research Station, Fort Collins, CO.

Evenden, A., M. Miller, M. Beer, E. Nance, S. Daw, A. Wight, M. Estenson, and L. Cudlip. 2002. Northern Colorado Plateau Vital Signs Network and Prototype Cluster, Plan for Natural Resources Monitoring: Phase I Report, October 1, 2002. [Two volumes]. National Park Service, Northern Colorado Plateau Network, Moab, UT. 138 p. plus appendices.

Foster, M. J. Stednick, W. Rice. 2000. Inventory and characterization of upland water resources in Dinosaur National Monument. Colorado State University, Watershed Science Program. Fort Collins, CO. 80 p.

Inglis, R. 1989. Pipe Spring National Monument aquifer test, Monitor Well No. 1. Ft. Collins, Colorado, National Park Service Report, 12 p.

Inglis, R., 1997. Monitoring and analysis of Spring Flow at Pipe Spring National Monument, Arizona. Ft. Collins, Colorado, National Park Service Technical Report NPS/NRWRD/NRTR-97125, 35 p.

Kunkle, S., W. S. Johnson, M. Flora. 1987. Monitoring stream water for land-use impacts: a training manual for Natural Resource Management Specialists. Water Resources Division, National Park Service, Fort Collins, CO.

MacDonald, L. H. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA-910/9-91-001. Environmental Protection Agency, Seattle, WA.

National Park Service. 2001. Handbook for Monitoring Vital Signs in National Parks, Water Quality Draft Guidance parts A, B, C, D and E. National Park Service, Natural Resource Program Center, available at http://science.nature.nps.gov/im/monitor/handbook.htm.

Rice, W. J. 1998. Water chemistry variation between lithologies in Dinosaur National Monument, Colorado. Masters Thesis. Colorado State University, Fort Collins, CO.

Sharrow, David. 1999. Addition and Removal of Water from Main Spring and Spring Room Spring. Memorandum from Hydrologist, Zion National Park to Superintendent, Pipe Spring National Monument dated November 2, 1999. 9 p.

Truini, Margot. 1999. Geohydrology of Pipe Spring National Monument Area, Northern Arizona. U.S. Geological Survey, Water Resources Investigations 98-4263, 25 p.

Table C-1. Participants in water quality and quantity vital signs workshop for the Northern Colorado Plateau Network, held April 10-11, 2003 in Moab, Utah.

PARTICIPANT	REPRESENTING
Mark Miller	Northern Colorado Plateau Network
Pete Penoyer	NPS – Water Resources Division, Ft. Collins
Norm Henderson	NPS – Colorado River Coordinator
Anne Brasher	USGS – WRD, Salt Lake City
Kevin Alexander	Western State College
Paul von Guerard	USGS – WRD, Grand Junction
Kelly Cahill	Bryce Canyon National Park
Dave Sharrow	Zion NP, Pipe Spring NM, & Cedar Breaks NM
Elizabeth Nance	Northern Colorado Plateau Network
Aneth Wight	Northern Colorado Plateau Network
Margaret Beer	Northern Colorado Plateau Network
Clay Kyte	Fossil Butte National Monument
Ed Krumpe	University of Idaho, Moscow
Tom Clark	Capitol Reef National Park
Matt Malick	Curecanti National Recreation Area
Lynn Cudlip	Western State College
Charlie Schelz	NPS - Southeast Utah Group
Tamara Naumann	Dinosaur National Monument
Juliane Brown	USGS – WRD, Denver
Sharon Day	USGS – WRD, Denver
Kirby Wynn	USGS – WRD, Grand Junction
Richard Denton	Utah Division of Water Quality
Lisa Thomas	Southern Colorado Plateau Network

Table C-2. Recommended water quality indicators for general designated use categories. (EPA; www.epa.gov/owow/monitoring/elements/elements.html#6)

	General Designated-Use Categories			
	Aquatic Life & Wildlife	**Recreation**	**Drinking Water**	**Fish/Shellfish Consumption**
Recommended Core Indicators	Condition of biological communities Dissolved oxygen Temperature pH Habitat assessment Flow Nutrients Landscape conditions (e.g. % cover of land uses) Additional indicators for lakes and wetlands: Eutrophic condition, hydrogeomorphic settings and functions	Pathogen indicators (*E.coli, enterococci*) Nuisance plant growth Flow Nutrients Chlorophyll Landscape conditions Additional indicators for lakes and wetlands: Secchi depth, hydrogeomorphic settings and functions	Trace metals Pathogens Nitrates Salinity Sediments/TDS Flow Landscape conditions	Pathogens Mercury Chlordane DDT PCBs Landscape conditions
Supplemental Indicators	Ambient toxicity Sediment toxicity Other chemicals of concern in water column or sediment Health of organisms	Other chemicals of concern in water column or sediment Hazardous chemicals Aesthetics	VOCs (in reservoirs) Hydrophylic pesticides Nutrients Other chemicals of concern in water column or sediment Algae	Other chemicals of concern in water column or sediment

Table C-3. Water-quality parameters pertinent to specific resource threats (adapted and updated from Kunkle et al. 1987).

Visitor Use	**Agriculture**	**Residential Development**	**Oil & Gas, Mining**
BOD Chloride Chlorine COD DO Flow Hardness Macroinvertebrates Microorganisms Nutrients Oil & Grease pH Specific conductance Settleable solids Surfactants Temperature Trace elements (metals) Turbidity	BOD Chloride COD DO Flow Macroinvertebrates Microorganisms Nutrients pH Specific conductance Temperature Total dissolved solids Total suspended solids Turbidity	BOD Chloride Chlorine COD DO Flow Hardness Macroinvertebrates Microorganisms Nutrients Oil & Grease pH Settleable solids Specific conductance Sulfate Surfactants Temperature Trace elements Turbidity	Alkalinity BOD Cations/Anions DO Flow Hardness Herbicides Hydrocarbons Oil & Grease pH Phenols Specific conductance Surfactants Temperature Total dissolved solids Total suspended solids Trace elements Turbidity

Table C-4. Association between water-quality and quantity issues and hydrologic characteristics within NCPN parks.

TYPE OF WATER RESOURCE	WATER-RESOURCE ISSUES						
	HUMAN CONTACT[1]	RECREATIONAL IMPACT[2]	ADJACENT AND INTERNAL DEVELOPMENT[3]	LIVESTOCK GRAZING[4]	THREATENED OR ENDANGERED SPECIES[5]	INSTREAM STANDARDS[6]	IMPACTS OF ADJACENT PUBLIC LAND[7]
Perennial	BLCA, CANY, CURE, CARE, DINO, ZION	CANY, CARE, CURE, TICA, ZION	ARCH, CANY, CARE, CURE, DINO, GOSP, ZION	BLCA, CANY, CARE, CURE, DINO, ZION	BLCA, CANY, CURE, DINO, ZION	BLCA, CURE, CARE, DINO, ZION	ARCH BRCA, CANY, CARE, CURE, DINO, FOBU TICA, ZION
Intermittent and Ephemeral	ARCH, FOBU, NABR	ARCH, BRCA, FOBU, GOSP, NABR	COLM, FOBU	ARCH, FOBU, NABR			COLM
Aquifers	TICA	ARCH, BRCA, CANY, CARE, COLM, DINO, PISP, ZION	BRCA, CARE, ZION				
Seeps, Springs, & Hanging Gardens		ARCH, BRCA, CANY, COLM, CARE, CURE, HOVE, PISP	ARCH, CANY, CEBR, COLM, CARE, CURE, HOVE, NABR, PISP	ARCH, BRCA, CANY, CARE CEBR, HOVE, NABR, PISP			ARCH, CANY, CEBR, COLM, CARE, CURE, HOVE
Tinajas	ARCH, CANY, CARE, ZION	ARCH, CANY, CARE, ZION		CARE			
Wetlands		BRCA		BRCA			BRCA

1 Includes Recreational activities associated with water such as swimming, wading, and obtaining drinking water where there is a concern for transmission of communicable diseases.
2 Includes impacts from recreational activities such as hiking, vehicle use, and human waste disposal.
3 Includes construction of such things as roads and buildings, and disposal of treated wastewater which can occur in or near the park.
4 Includes impacts from livestock grazing inside or outside of the park.
5 Includes impacts that might occur to aquatic or riparian habitats of sensitive, threatened or endangered species.
6 Includes the development of source-specific water quality standards under the anti-degradation provisions of the Clean Water Act.
7 Includes impacts from activities that typically occur on public lands adjacent to the park, such as grazing, mining, off-road vehicle use, recreation and oil and gas development.

Park Acronyms:

ARCH = Arches National Park,
BLCA = Black Canyon of the Gunnison National Park,
BRCA = Bryce Canyon National Park,
CANY = Canyonlands National Park,
CARE = Capitol Reef National Park,
CEBR = Cedar Breaks National Monument,
COLO = Colorado National Monument,
CURE = Curecanti National Recreation Area,
DINO = Dinosaur National Monument,
FOBU = Fossil Butte National Monument,
GOSP = Golden Spike National Historic Site,
HOVE = Hovenweep National Monument,
NABR = Natural Bridges National Monument
PISP = Pipe Spring National Monument,
TICA = Timpanogos Cave National Monument, and
ZION = Zion National Park

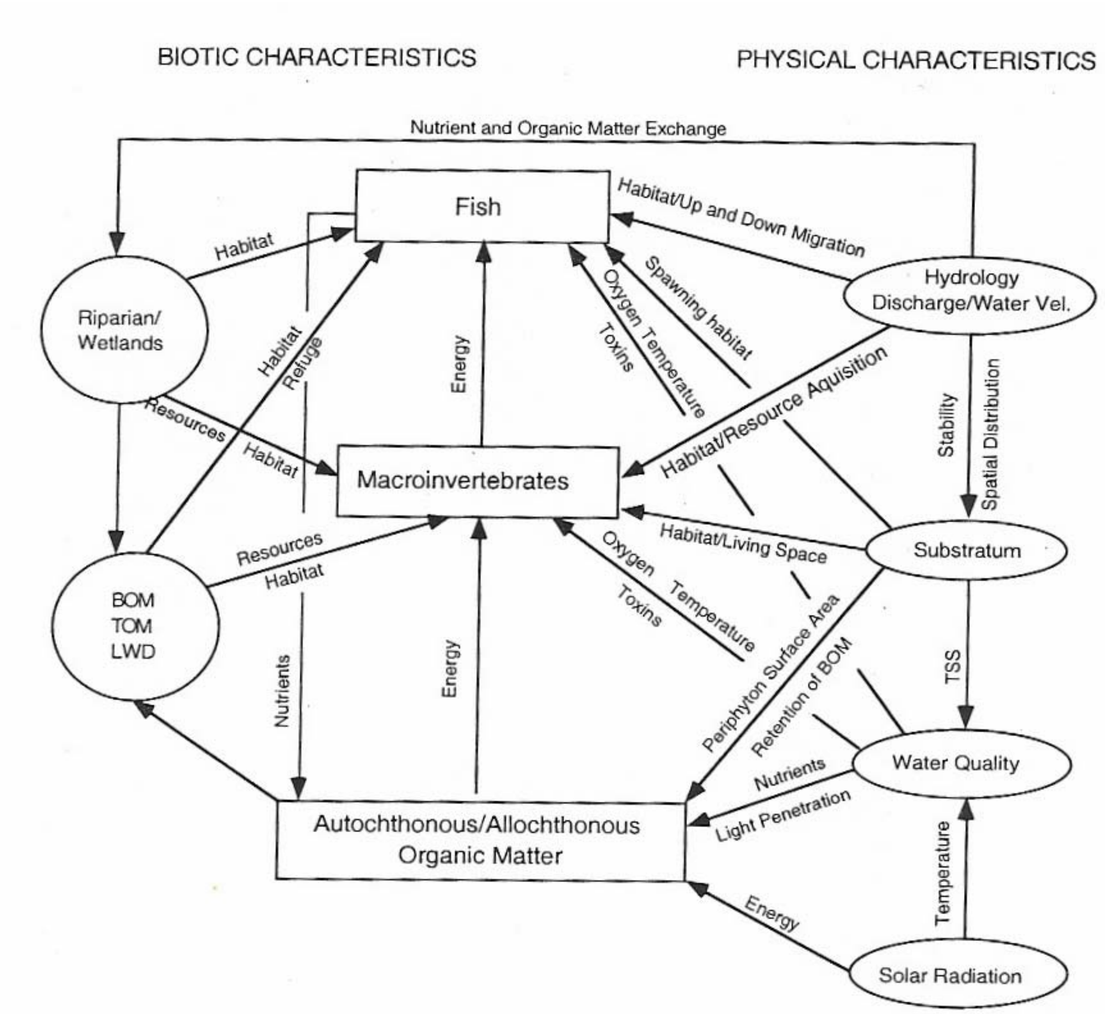


Figure C-1. Model of stream ecosystem identifying major biotic and abiotic components. River hydrology serves as a major driver for both water quality and the stream biota. Macroinvertebrates may serve as an excellent indicator of change in river hydrology and water quality (adapted from Davis et al. 2001).

Appendix D. Protected Uses for Northern Colorado Plateau Parks in Utah, Wyoming, Arizona and Colorado

Prepared by:

Dave Sharrow, NPS Zion National Park

17 September 2003

The following tables summarize protected uses as identified by the states of Utah, Wyoming, Arizona, and Colorado for Northern Colorado Plateau Parks. Numeric standards for water quality are specific to these protected uses.

Table D-1. Protected uses designated for Northern Colorado Plateau Parks in Utah.

UTAH PARK UNIT	WATERS IN PARK	REFERENCE TO STATE SEGMENT	Utah High Quality Cat. 2[1]	UTAH PROTECTED USES (See Table D-5 for Definitions of Use Codes)						
				1C	2B	3A	3B	3C	3D	4
Hovenweep NM	All	San Juan River								
Bryce Canyon NP	East	Paria River								
	West	East Fork Sevier River, Annabelle Diversion to headwaters and Tropic Res.								
Zion NP	Kolob Area (Taylor Creek, Camp Creek)	Ash Creek above Ash Creek Res.								
	North Fork Virgin River and tributaries.	North Fork Virgin River confluence w/ E. Fork to headwaters								
	East Fork Virgin River	East Fork Virgin River confluence w/ N. Fork to headwaters								
	Kolob Creek	Kolob Creek, confluence with N. Fork V. R. to headwaters								
	Kolob Reservoir & Navajo Lake (both outside Park)	Kolob Reservoir and Navajo Lake								

Table D-1 continued.

UTAH PARK UNIT	**WATERS IN PARK**	**REFERENCE TO STATE SEGMENT**	Utah High Quality Cat. 2[1]	**UTAH PROTECTED USES** (See Table D-5 for Definitions of Use Codes)						
				1C	2B	3A	3B	3C	3D	4
Zion NP	North Creek, Coalpits Wash	Virgin River upstream of Quail Creek Diversion								
	LaVerkin Creek	Virgin River below Quail Creek Diversion								
Cedar Breaks NM	West Slope	Coal Creek and tributaries								
	East Slope	Duck Creek and tributaries								
Timpanogos Cave NM	All	American Fork River								
Dinosaur NM	See Table W2-4 below									
Natural Bridges NM	All (White Canyon)	Lake Powell and all tributaries								
Golden Spike NHS	Blue Creek	Blue Creek from Great Salt Lake to Blue Cr. Res.								
Capitol Reef NP	Fremont R. Downstream of CARE (Harnet Draw, Sandy & Oak Cr. in park)	Fremont River and tributaries from the confluence with Muddy Cr. To CARE								
	Fremont River in CARE and upstream	Fremont River and tributaries through CARE to Headwaters								
	Pleasant Creek inside CARE	Pleasant Creek and tributaries, from confluence with Fremont River to E. boundary of CARE								
	Pleasant Cr. upstream of CARE (outside of Park)	Pleasant Cr. and tributaries from east boundary of Capitol Reef to headwaters								
	Halls Creek (Bitter Cr. Divide South in park)	All tributaries to Lake Powell except as listed separately								
	Southwestern Margin of park	Escalante River and tributaries, from Lake Powell to confluence with Boulder Creek								
Arches NP	All	Colorado R. and tributaries from Lake Powell to state line								

Table D-1 continued.

UTAH PARK UNIT	WATERS IN PARK	REFERENCE TO STATE SEGMENT	Utah High Quality Cat. 2[1]	UTAH PROTECTED USES (See Table D-5 for Definitions of Use Codes)						
				1C	2B	3A	3B	3C	3D	4
Canyonlands NP	Most of Park	Colorado R. and tributaries from Lake Powel l to state line, and Green River and tributaries from confluence with Colorado R. to State Line								
	Immediate vicinity of Indian Cr. confluence and southeastern-most margin of park.	Indian Creek and tributaries from confluence with Colorado R. to Newspaper Rock State Park								
	Southwestern-most margin of park	All Tributaries to Lake Powell except as listed separately								

[1] High Quality category 2 designation in Utah does not carry with it specific numeric criteria at this time.

Table D-2. Protected uses designated for Northern Colorado Plateau Parks in Wyoming.

Wyoming				
Park	**Waters in Park**	**Reference to State Segment**	**Class**	**Protected Uses**
Fossil Butte NM	All	Chicken Creek, tributary to Twin Creek and Bear River in Lincoln County	3B	Scenic Value, Industry, Agriculture, Wildlife, Recreation, Other Aquatic Life (NOT Protected are: Drinking Water, Game Fish, Non-Game Fish, and Fish Consumption)

Table D-3. Protected uses designated for Northern Colorado Plateau Parks in Arizona.

Arizona			
Park	**Waters in Park**	**Reference to State Segment**	Protected Uses
Pipe Spring NM	All	Kanab Creek	Aquatic and Wildlife warm water, Full-body Contact, Domestic Water Source, Fish Consumption, Agricultural Irrigation

Table D-4. Protected uses designated for Northern Colorado Plateau Parks in Colorado (including portions of Dinosaur National Monument in Utah).

Segment Description	Water Body Identification Code (305b Water Body Identification Code) [1]	Miles (In Park)	Shoreline Miles [2]	Acres (In Park)	State-Designated Uses Applied to this Segment (See Table W2-5 for Definitions of Use Codes)											
					Colorado							Utah				
					AG	ALCW1	ALCW2	ALWW2	DWS	RPC	RSC	1C	2B	3A	3B	4
Dinosaur National Monument																
Mainstem of the Yampa River from a point immediately above the confluence with Lay Creek to the confluence with the Green River.	COLCLY02 (COLCLY02_8100)	48.23		2.92												
All Tributaries to the Yamps River, including all wetlands, lakes and reservoirs from a point immediately below the confluence with Lay Creek to a point immediately below the confluence with the Little Snake River.	COLCLY14 (COLCLY14_8100)	230.98														
Mainstem of the Green River within Colorado (Moffatt County)	COLCLY19 (COLCLY19_7800)	25.32		48.65												
All tributaries to the Green River in Colorado, including all wetlands, lakes and reservoirs, except for the specific listings in segments 21 and 22; all tributaries of the Yampa River from a point immediately below the confluence with the Green River, except for the specific listings in segments 15 through 18.	COLCLY20 (COLCLY20_7800)	74.28														
All Tributaries to the White River, including all wetlands, lakes and reservoirs, from a point immediately above the confluence with Douglas Creek to the Colorado/Utah border, except for the specific listing in Segment 23.	COLCWH22 (COLCWH22_8500)	0.99														

Table D-4 continued.

Segment Description	Water Body Identification Code (305b Water Body Identification Code)[1]	Miles (In Park)	Shoreline Miles[2]	Acres (In Park)	State-Designated Uses Applied to this Segment (See Table W2-5 for Definitions of Use Codes)											
					Colorado							Utah				
					AG	ALCW1	ALCW2	ALWW2	DWS	RPC	RSC	1C	2B	3A	3B	4
Dinosaur National Monument																
Green River and tributaries from the confluence with Colorado River to State Line, except for the two segments listed below.	UT-R-GREEN-0001 (UT14060001-001_00)	140.18	0.5	4.68												
Big Brush Creek and tributaries from confluence with Green River to Tyzack (Red Fleet) Dam.	UT-R-GREEN-0034 (UT14060002-003_00)	0.95														
Jones Hole Creek and Tributaries from confluence with Green River to headwaters.[3]	UT-R-GREEN-0036 (UT14060001-002_00)	6.33														
Black Canyon of the Gunnison National Park																
Mainstem of the Gunnison River from the outlet of Crystal Reservoir to a point immediately above the confluence with the Uncompahgre River	COGULG01 (COGULG01_6800)	11.93														
All tributaries to the Gunnison River, including all wetlands which are not on national forest lands, from the outlet of Crystal Reservoir to the confluence with the Colorado River, except for specific listings in the North Fork and Uncompahgre River subbasins and in Segments 3, 4b, 5 through 10, 12 and 13.	COGULG04A (COGULG04_6800)	16.15														
Curecanti National Recreation Area																
Mainstem of the Gunnison River from the outlet of Crystal Reservoir to a point immediately above the confluence with the Uncompahgre River	COGULG01 (COGULG01_6800)	2.26														

Table D-4 continued.

Segment Description	Water Body Identification Code (305b Water Body Identification Code) [1]	Miles (In Park)	Shoreline Miles [2]	Acres (In Park)	State-Designated Uses Applied to this Segment (See Table W2-5 for Definitions of Use Codes)											
					Colorado							Utah				
					AG	ALCW1	ALCW2	ALWW2	DWS	RPC	RSC	1C	2B	3A	3B	4
Curecanti National Recreation Area																
All tributaries to the Gunnison River, including all wetlands which are not on national forest lands, from the outlet of Crystal Reservoir to the confluence with the Colorado River, except for specific listings in the North Fork and Uncompahgre River subbasins and in Segments 3, 4b, 5 through 10, 12 and 13.	COGULG04A (COGULG04A_6800)	0.60														
Mainstem of the Gunnison River from the confluence of the East and Taylor rivers to the inlet of Blue Mesa Reservoir.	COGUUG14 (COGUUG14_6800)	4.61	5.34	169.10												
Blue Mesa, Morrow Point and Crystal Reservoirs and those segments of the Gunnison River which inter-connect reservoirs.	COGUUG25 (COGUUG25_6800)	64.05	100.30	9421.83												
All tributaries, from the source, to those waters described in segment 25 including all lakes, reservoirs and wetlands which are on Gunnison and Uncompahgre National Forest lands, or which flow into or are present within Curecanti National Recreation Area with the exception of Segments 1, 2, 3, 14, and 29 through 32.	COGUUG26 (COGUUG26_6800)	19.88	3.90	67.27												
Mainstem of Lake fork of the Gunnison including all tributaries, lakes, reservoirs and wetlands from the source to Blue Mesa Reservoir, except for the specific listing in Segments 3, 30, 31, and 32.	COGUUG29 (COGUUG29_6800)	9.68	16.01	533.58												

Table D-4 continued.

Segment Description	Water Body Identification Code (305b Water Body Identification Code) [1]	Miles (In Park)	Shoreline Miles [2]	Acres (In Park)	State-Designated Uses Applied to this Segment (See Table W2-5 for Definitions of Use Codes)											
					Colorado							Utah				
					AG	ALCW1	ALCW2	ALWW2	DWS	RPC	RSC	1C	2B	3A	3B	4
Colorado National Monument																
All Tributaries to the Colorado River, including all wetlands, lakes and reservoirs, from a point immediately below the confluence of Parachute Creek to the Colorado/Utah border except for the specific listings in segments 13b through 19.	COLCLC13A (COLCLC13A_6500)	54.46														

[1] The Water Body Identification Code is a state-assigned identifier for each reach. The Water Body Identification Codes used in 303d reports may include more than one WBID, or may include only a part of one WBID.
[2] Shoreline Miles applies to adjacent lakes/ponds, seas/oceans, swamps/marshes, reservoirs or estuaries.
[3] Utah also designates Jones Hole Creek as High Quality Category 2, which provides narrative standards for antidegradation.

Table D-5. Definitions of Colorado and Utah designated protected uses.

State-Designated Use Code	State-Designated Use	Definition
Colorado		
AG	Agriculture	These surface waters are suitable or intended to become suitable for irrigation of crops usually grown in Colorado and which are not hazardous as drinking water for livestock.
ALCW1	Aquatic Life Cold Water-Class 1	These are waters that (1) currently are capable of sustaining a wide variety of cold water biota, including sensitive species, or (2) could sustain such biota but for correctable water quality conditions. Waters shall be considered capable of sustaining such biota where physical habitat, water flows or levels, and water quality conditions result in no substantial impairment of abundance and diversity of species.
ALCW2	Aquatic Life Cold Water-Class 2	These waters are not capable of sustaining a wide variety of cold water biota, including sensitive species, due to physical habitat, water flows or levels, or uncorrectable water quality conditions that result in substantial impairment of the abundance and diversity of species.
ALWW2	Aquatic Life Warm Water-Class 2	These waters are not capable of sustaining a wide variety of warm water biota, including sensitive species, due to physical habitat, water flows or levels, or uncorrectable water quality conditions that result in substantial impairment of the abundance and diversity of species.
DWS	Domestic Water Supply	These surface waters are suitable or intended to become suitable for potable water supplies. After receiving standard treatment (defined as coagulation, flocculation, sedimentation, filtration and disinfection with chlorine or its equivalent) these waters will meet Colorado drinking water regulations and any revisions, amendments or supplements thereto.
RPC	Recreation Primary Contact	These surface waters are suitable or intended to become suitable for recreational uses in or on the water when the ingestion of small quantities of water is likely to occur. Such waters include but are not limited to those used for swimming, rafting, kayaking and water-skiing.
RSC	Recreation Secondary Contact	These surface waters are suitable or intended to become suitable for recreational uses on or about the water which are not included in the primary contact subcategory, including but not limited to fishing and other streamside or lakeside recreation.

Table D-5 continued.

State-Designated Use Code	State-Designated Use	Definition
Utah		
1C	Drinking Water Supply	Protected for domestic purposes with prior treatment by processes as required by the Utah Department of Health.
2A	Primary Contact (Recreation)	Protected for primary contact recreation such as swimming.
2B	Secondary Contact (Recreation)	Protected for secondary contact recreation such as boating, wading, or similar uses.
3A	Cold Water Game Fish	Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.
3B	Warm Water Game Fish	Protected for warm water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.
3C	Nongame Fish	Protected for nongame fish and other aquatic life, including the necessary aquatic organisms in their food chain.
3D	Waterfowl	Protected for waterfowl, shore birds and other water-oriented wildlife not included in Classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain.
3E	Severely Habitat Limited	Severely habitat limited waters. Narrative standards will be applied to protect these waters for aquatic wildlife.
4	Agriculture	Protected for agricultural uses including crop irrigation and stock watering.
5	Great Salt Lake	Protected for primary and secondary contact recreation, aquatic wildlife, and mineral extraction.

Sources: Adapted from National Park Service 2003a, 2003b, 2003c, and 2003d, which used Environmental Protection Agency WQSDB (Version 3), and State of Utah, 1997 as primary sources.

Sources

Environmental Protection Agencys 2003. National Water Quality Standards Database. Fourth release. EPA, Washington D.C. Available at http://www.epa.gov/wqsdatabase/.

National Park Service. 2003a. Clean Water Act Water Quality Designated Uses and Impairments; Black Canyon of the Gunnison National Park. National Park Service, Ft. Collins, Colorado, Technical Report NPS/NRWRD/NRTR-2003/303, 13 p.

National Park Service. 2003b. Clean Water Act Water Quality Designated Uses and Impairments; Colorado National Monument. National Park Service, Ft. Collins, Colorado, Technical Report NPS/NRWRD/NRTR-2003/304, 13 p.

National Park Service. 2003c. Clean Water Act Water Quality Designated Uses and Impairments; Curecanti National Recreation Area. National Park Service, Ft. Collins, Colorado, Technical Report NPS/NRWRD/NRTR-2003/305, 17 p.

National Park Service. 2003d. Clean Water Act Water Quality Designated Uses and Impairments; Dinosaur National Monument. National Park Service, Ft. Collins, Colorado, Technical Report NPS/NRWRD/NRTR-2003/306, 21 p.

State of Arizona. 1996. Arizona Administrative Code, title 18. Environmental Quality, Chapter 11. Department of Environmental Quality Water Quality Standards. Appendix B. List of Surface Waters and Designated Uses. State of Arizona, Phoenix.

State of Utah. 1997. Standards of Quality for Waters of the State, R317-2, Utah Administrative Code. Utah Dept of Environmental Quality, Div. of Water Quality. Revised December 19, 1997. State of Utah, Salt Lake City.

State of Wyoming. 2000. Wyoming Surface Water Quality Standards, Water Quality Rules and Regulations, Table B, Surface Water Classification List. State of Wyoming, Cheyenne.

Appendix E. USGS Progress Report on Protocol Development for the Northern Colorado Plateau Prototype Cluster

Prepared by:

Jayne Belnap
Tim Graham
Sarah Willbrand
Jessica Reilly
Rich Alward
Sue Phillips

U.S. Geological Survey
Southwest Biological Science Center
Canyonlands Field Station
2290 S. West Resource Blvd.
Moab, UT 84532

15 August 2003

Introduction

The National Park Service (NPS) units of the Northern Colorado Plateau (NCP) Prototype Cluster[1] identified three high-priority monitoring themes to be addressed in the prototype program. These themes include (1) ecosystem structure and function (also encompassing climate and landscape structure and function), (2) invasive exotic plants, and (3) threatened, endangered, and sensitive (TES) taxa (i.e., species of special concern). Together, these provide a thematic framework for the NCP prototype program (Fig. E-1).

The U.S. Geological Survey, Biological Resources Division (USGS-BRD), Canyonlands Field Station, is a partner in the development of monitoring protocols for the NCP prototype cluster and is responsible for addressing scientific-research needs associated with protocol development. Protocols acquired or developed by USGS-BRD for the monitoring themes identified above will be exportable to all parks in the Northern Colorado Plateau Network (NCPN).

[1] Prototype parks include Canyonlands National Park (CANY), Arches National Park (ARCH), Capitol Reef National Park (CARE), Dinosaur National Monument (DINO), and Natural Bridges National Monument (NABR).

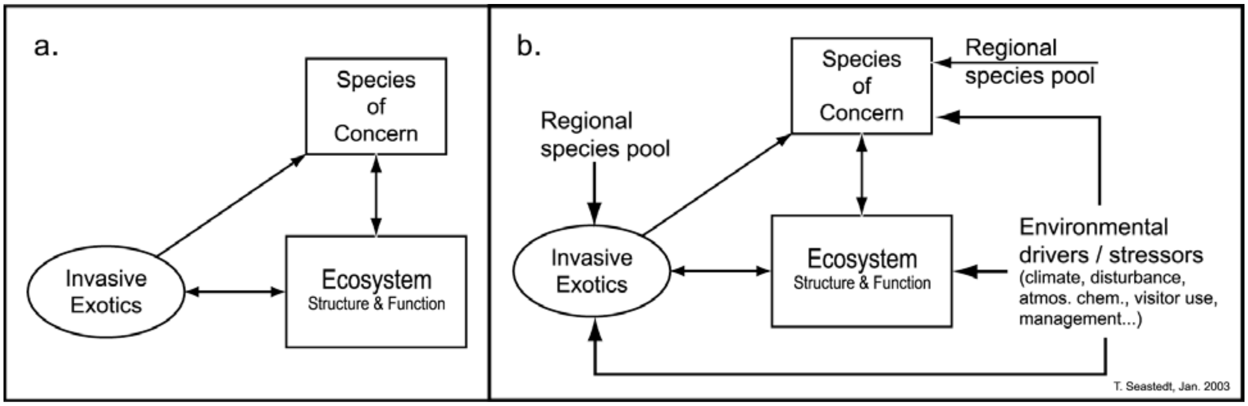


Figure E-1. Monitoring themes (a) of the Northern Colorado Plateau Prototype Cluster, and (b) ecological factors influencing these themes.

Objectives

Following are general objectives for USGS-BRD protocol-development work:

- Develop (or acquire) monitoring protocols required for themes of the NCP prototype cluster.
- Test monitoring protocols as needed through pilot-implementation studies.
- Conduct research to verify linkages between monitoring indicators (vital signs) and ecological processes and attributes.
- Conduct research to evaluate indicator variability and responsiveness of indicators (and associated ecological attributes) to management
- Conduct research to assist in the determination of management thresholds for monitoring indicators.
- Periodically review and revise protocols for prototype parks after they have become operational.
-

Vital Sign Selection and Protocol Development

<u>Theme 1: Ecosystem Structure and Function</u>

To aid indicator (vital-sign) identification and protocol development for ecosystem monitoring, in FY 2002 the NCP prototype adopted a general conceptual model developed by Chapin and colleagues (1996) for purposes of describing principles of ecosystem sustainability (Fig. E-2a). The “interactive-control model” identifies four controls of ecosystem structure and function that should be included in a monitoring program oriented towards ecosystem sustainability. These are (1) soil and water resources (including water quality for aquatic ecosystems), (2) atmospheric resources and conditions (including air quality and climate), (3) disturbance regimes, and (4) biotic functional groups. The four interactive controls are constrained by the five *state factors* of Jenny (1941, 1980) – climate, potential biota, topography, parent material, and time since disturbance. For ecosystem monitoring, a key aspect of this model is the hypothesis that interactive controls must be conserved within their natural range of variability for the ecosystem to be sustained. Large changes in any of the four interactive controls alter key ecosystem processes and result in a new ecosystem characterized by different structural and functional attributes than the original system (Chapin et al. 1996). For example, major changes in soil resources (e.g., through erosion, salinization, fertilization, or other mechanisms) can greatly affect nutrient cycling and primary production, and thus can result in major changes in terrestrial ecosystem structure and function. Soil-resource alteration is one of the most common mechanisms by which human activities affect ecosystem sustainability (Chapin et al. 1996, Whitford 2002). In Figure E-2b, stressors affecting NCPN ecosystems are arranged around the model in relation to their first-order effects and degree of potential control by park management.

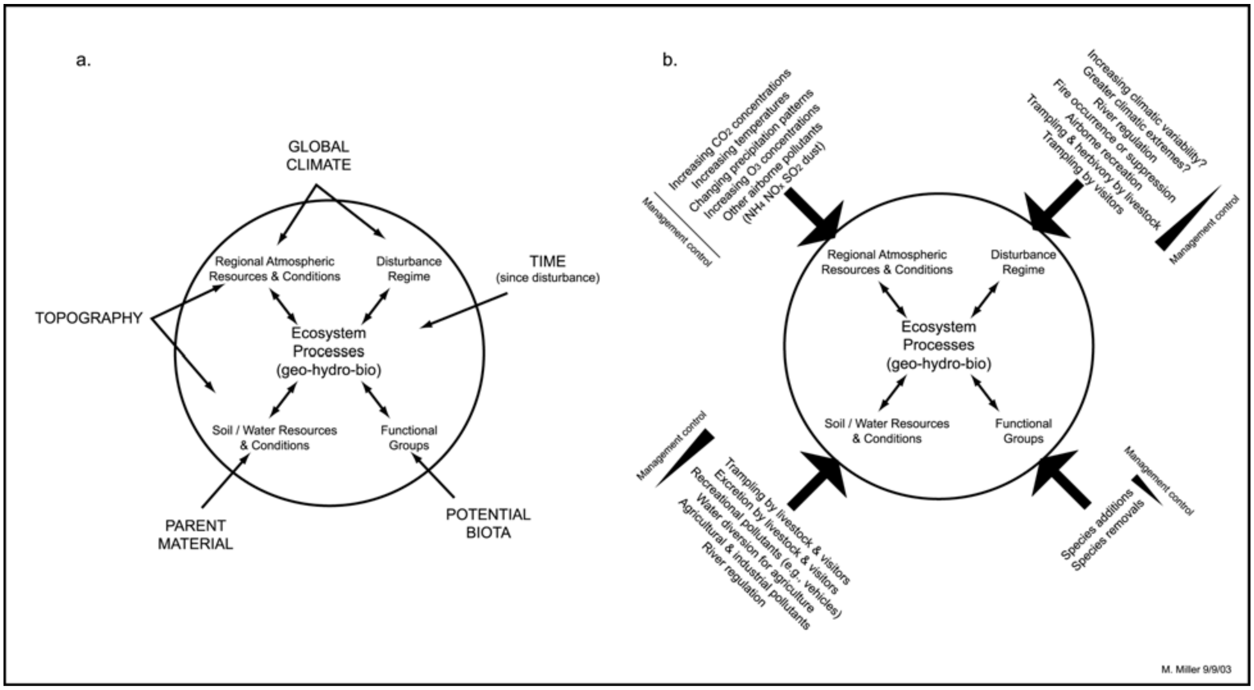


Figure E-2. The interactive-control model (a) of ecosystem sustainability. The diagram illustrates relationships among state factors (outside perimeter), interactive controls (inside perimeter), and ecosystem processes (center). The circle represents the boundary of the ecosystem (adapted from Chapin et al. 1996). In (b), stressors affecting NCPN ecosystems are arranged in relation to their first-order effects and degree of potential control by park management.

On the basis of the interactive control model, elements of Theme 1 are identified below in Figure E-3. This theme encompasses terrestrial, riparian, and aquatic ecosystems, landscape-level linkages among these systems, and ecosystem components or conditions associated with the interactive controls of ecosystem structure and function. As described below, protocol-development work to date has focused primarily on arid-semiarid terrestrial ecosystems, though with this current funding cycle we are expanding this effort to include riparian ecosystems, aquatic ecosystems, and methods of landscape-level monitoring.

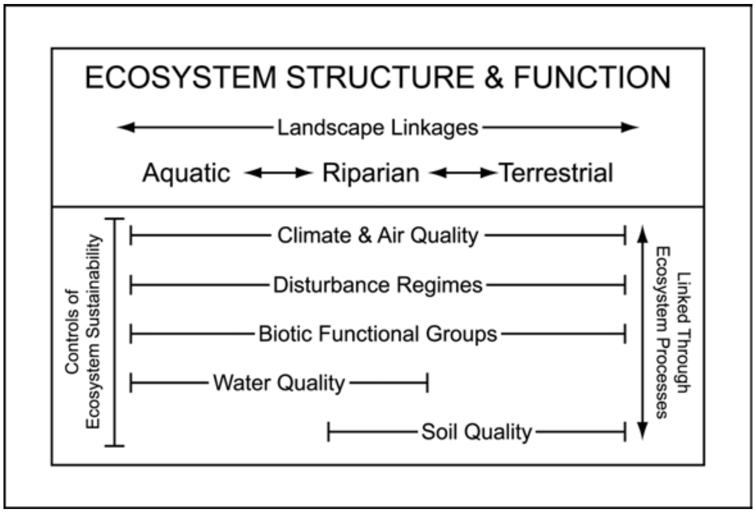


Figure E-3. Elements of the ecosystem-structure-and-function monitoring theme of the Northern Colorado Plateau Prototype Cluster.

Soil, Water, and Nutrient Dynamics

Primary ecosystem processes that must be functional to ensure the sustainability of terrestrial ecosystems are (a) the capture and retention of water (hydrologic function), (b) the capture and retention of nutrients (nutrient cycling), and (c) the capture and retention of photosynthetic energy in organic materials. Degraded ecosystems are characterized by accelerated rates of water, nutrient, and organic-matter losses compared with similar ecosystems relatively unaffected by human activities. We have merged these concepts into two, more simple indicators that the NPCN will focus on:

A. *Hydrologic function* (upland systems) – capacity of a site to capture, store, and safely release water from rainfall, run-on, and snowmelt, to resist a reduction in this capacity, and to recover this capacity following degradation (Pellant et al. 2000).

B. *Soil / site stability* – the capacity of a site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (Pellant et al. 2000).

Although all four controls interactively affect the functioning of these three primary processes, *soil* and *biological soil crusts* play disproportionate roles and thus are essential for the sustainability of terrestrial ecosystems. Soil is a fundamental resource because it functions as a medium for water capture and retention, nutrient cycling and retention, and primary production. Soil properties that *affect* functioning of primary ecosystem processes and are *effected by* management activities (hence subject to monitoring for change detection) include stability (susceptibility to erosion by wind and water), structure, organic-matter content and fertility, biotic activity, surface roughness, and surface crusting (biotic or physicochemical). Because of their capacity for change in relation to management, these are referred to as *dynamic soil properties*. In most arid-semiarid ecosystems, especially those of the Colorado Plateau, biological soil crusts (composed primarily of cyanobacteria, mosses, and lichens) are an integral part of, and thus influence, all the soil properties listed above. They are critical in the stabilization of soils, in providing organic matter and soil structure, in adding and maintaining soil fertility and in influencing local hydrologic cycles. In addition, they are highly responsive to management actions. Consequently, 3 of the 28 high-priority vital signs, and 10 of the 52 measures of the vital signs identified by NPCN concern biological crust measures. For this reason, much of the protocol development activities for soil, water, nutrient dynamics have been focused on biological soil crusts.

There were two main challenges inherent in developing biological soil crusts as vital signs or measures of vital signs. The first was to develop methods for measuring soil crusts in easy, non-technical, repeatable, and non-destructive ways. The second was determining what crust development stage should trigger management action for a particular vital sign, and tying this, using solid solid science, to ecosystem function in a highly defensible manner.

Much research has been done on the ecosystem roles played by biological soil crusts on the Colorado Plateau and other western US desert regions. These studies have demonstrated that the presence of well-developed lichen-moss soil crusts preclude soil loss by wind (Figures E-4 and E-5) and water (Barger 2003) and enhances the nutrient status of soils (Evans and Ehleringer 1993). The presence of these well-developed soil crusts also increases local water infiltration (Barger 2003). In addition, well-developed crusts are destroyed by trampling or vehicle traffic. Therefore, their presence indicates that soil aggregate structure, compaction levels, soil food webs and associated nutrient cycles are healthy and functioning at a high level. Most of the above studies compared well-developed soil crusts to adjacent, recently disturbed areas with no or very low crust cover, where wind and water erosion readily removed soils, soils were compacted, structure destroyed, and soil nutrients were lower as a result of the disturbance. However, there had been no work on understanding what level of soil crust development was necessary to maintain soil stability, structure and fertility at a minimum sustainable level and/or acceptable to land managers. To address these two issues, we have done the following:

A. *Measuring Soil Crust Development*: Assessment of the developmental stage of biological soil crusts has traditionally been done estimating total crust cover, cover by species, and/or estimating biomass of cyanobacteria using chlorophyll a or nitrogen-fixation potential. However, the first method requires hard-to-find technical expertise and the find a more simple approach. Using volunteers consisting of non-biologists second is both destructive and requires sophisticated equipment. Therefore, we set out to find a more simple approach. Using volunteers consisting of non-biologists (administrative staff, park rangers, etc.) and biologists, we tested a variety of methods for ascertaining crust development stage that was non-destructive and non-technical, but repeatable using untrained personnel. We found that people were consistently able to tell about different levels of soil darkness when given a set of photos to compare to the samples (Figure E-6).

B. *Soil Darkness, Soil Stability, and Ecosystem Function*: We then analyzed samples of different darkness levels and found a consistent correlation between sample darkness and cyanobacterial biomass as estimated by chlorophyll a (Figure E-7), soil aggregate stability as estimated by the slake test (Figure E-8), and soil stability as estimated by polysaccharide concentrations in the soil (Figure E-9). These results are very exciting, as previous studies in this and other desert ecosystems have shown a positive correlation between cyanobacteria biomass and resistance to wind erosion (Belnap and Gillette 1997, 1998, McKenna-Neuman and Maxwell 1996, Belnap et al. 2003) and between soil aggregate stability as estimated by the slake test and resistance to water erosion (Herrick et al. 2001, Barger 2003). Because polysaccharides are the materials that bind soil particles together, their concentrations should also indicate resistance to water and wind erosion, although this connection had not yet been studied.

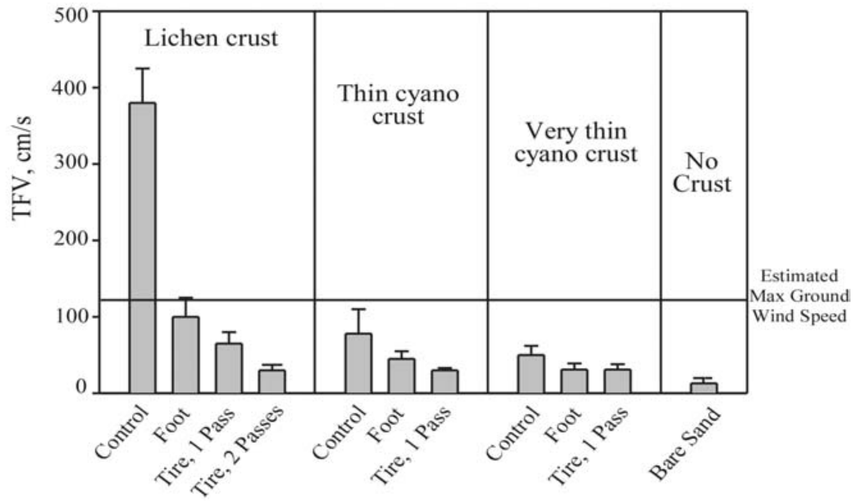


Figure E-4. Threshold friction velocities (the wind speed that moves soil particles) for sandy soils with different levels of biological crust cover near Moab, UT. Note that soils with well-developed lichen crusts are much more stable than soils with a thin or very thin cyanobacterial crust, or no crust cover. This shows that soils that lack lichen soil crusts are vulnerable to wind erosion.

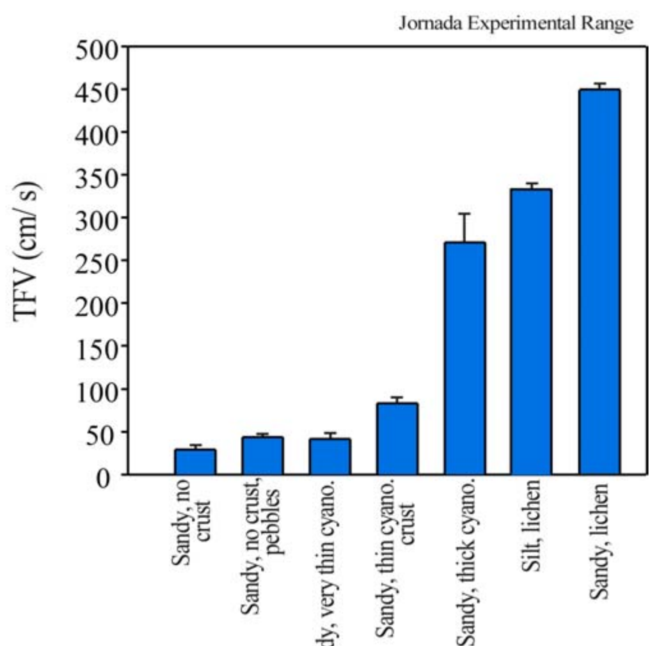


Figure E-5. Threshold friction velocities for different soils (sandy, silty) with different biological soil crust covers near Las Cruces, NM. Note that soils without thick cyanobacterial or lichen crusts are vulnerable to wind erosion.

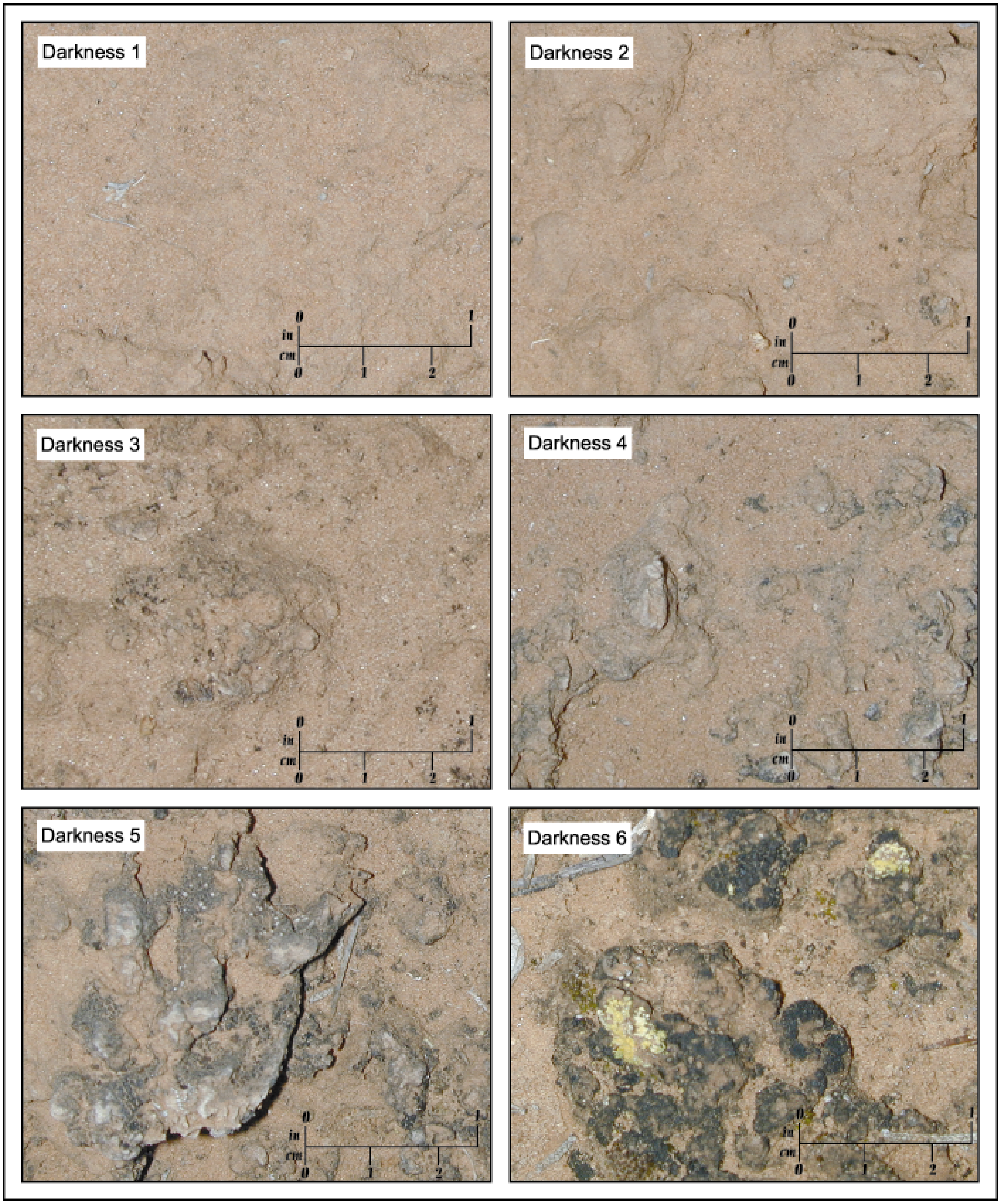


Figure E-6. Visual categories of crust darkness used in crust condition assessment.

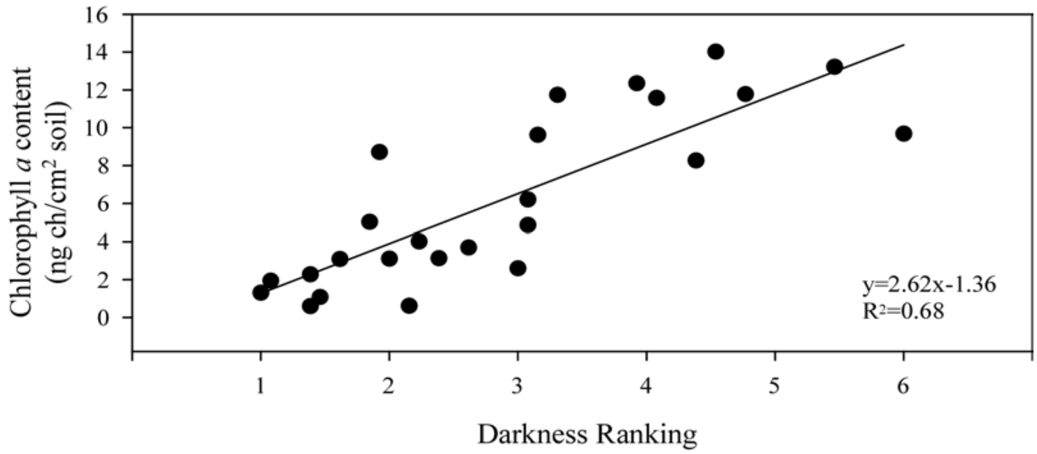


Figure E-7. The relationship between chlorophyll a content and the visual categories of biological soil crust darkness.

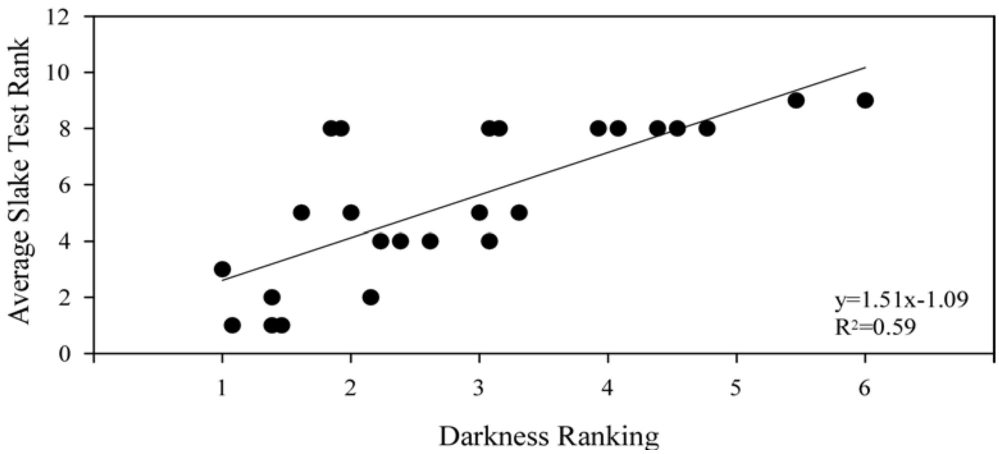


Figure E-8. The relationship between the slake test (see text) and the visual categories of biological soil crust darkness.

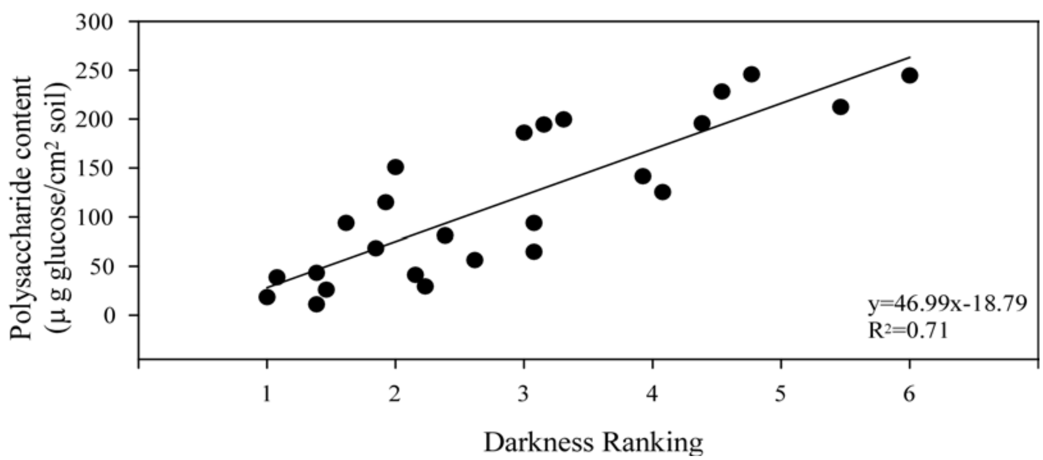


Figure E-9. The relationship between polysaccharide content and the visual categories of biological soil crust darkness.

C. *Wind Erosion*: We then tested the relationship between the soil darkness index and the resistance of soil to wind erosion using a wind tunnel on both sandy (Figure E-10) and silty loam (Figure E-11) soils. These results indicate that there are 3 thresholds apparent in wind resistance of soils covered by soil crusts. Whereas soils in crust categories 1 and 2 are easily erodible at most wind speeds, and those in crust categories 5 and 6 are not erodible even under high wind speeds, those in categories 3 and 4 are susceptible to erosion during moderately high to high wind speeds. Sandy and silty loam soils were very similar. Therefore, it is suggested that soil crusts with a development level of 4 or less be considered a management for risk to wind erosion. During a separate study in the Mojave Desert, we also found a correlation between wind erodibility and chlorophyll content (Figure E-12). Because chlorophyll content is highly correlated with our darkness index, we believe this approach will also work in the Mojave Desert region.

D. *Water Erosion*: We have begun similar tests with a rainfall simulator. We have started testing soils in category 1 and 2 and those in category 5 and 6. Preliminary data indicate that, similar to wind erosion, category 1 and 2 soils are easily eroded and category 5 and 6 soils are almost impossible to erode. We will be testing category 3 and 4 soils this fall to determine appropriate management trigger thresholds.

E. *Water Infiltration/Hydrologic Function*: To establish appropriate management thresholds for water infiltration and hydrologic function, we have begun developing and testing a visual categorization of crusts combining darkness and surface roughness. Once we establish categories that are reliably separated by people of varying technical skill, we will use the rainfall simulator to identify management trigger thresholds.

F. *Silt Fences*: We have tested the efficacy of using silt fences to measure sediment production via water erosion from slopes. They have worked wonderfully, being simple, cheap, reliable and easy to use. We are currently installing silt fences under slopes dominated by crusts in categories 1-2, 3-4, and 5-6. This will enable us to field test the rainfall simulator results (section D, above).

G. *Nutrient Cycling and Soil Food Webs*: We have tested nitrogen fixation in soils covered by crust categories 1-2 and categories 5-6, and have found fixation rates are much higher in the latter category. We have also measured soil food web components (nematodes, protists, bacteria, and fungi) under categories 1-2 and 5-6, and found that the darker crusts have more diversity and greater abundance of species than the lighter categories. This implies that decomposition is faster, and therefore nutrients ,pre availabile to plants, in the darker crusts than the lighter crusts. In FY04, we will test crust categories 3-4 to determine management trigger thresholds for both nitrogen fixation and soil food web composition.

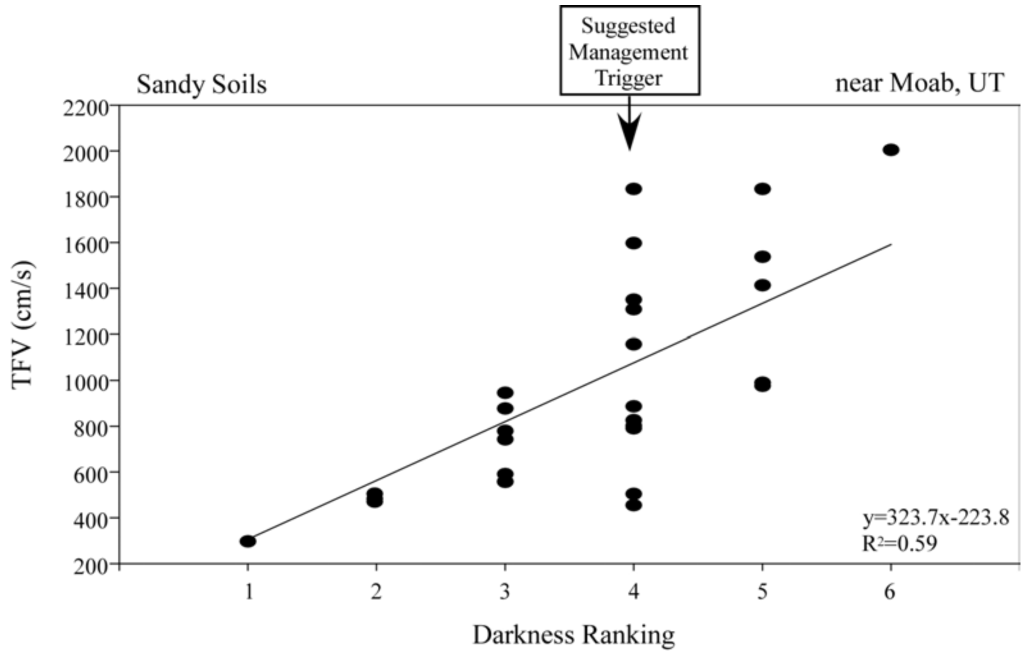


Figure E-10. The relationship between the darkness of biological soil crusts on sandy soils and wind erodibility, as indicated by threshold friction velocities. Because visual class 4 has TFV values that are vulnerable to wind erosion, crust in or below this class (1-4) should trigger management action.

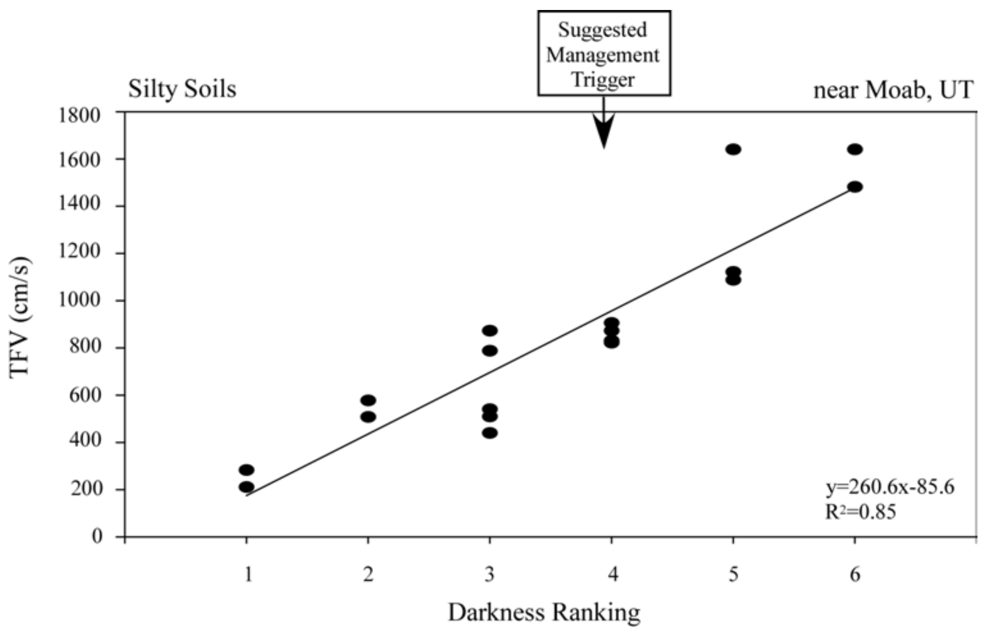


Figure E-11. The relationship between the darkness of biological soil crusts on silty soils and wind erodibility, as indicated by threshold friction velocities. Because visual class 4 has TFV values that are vulnerable to wind erosion, crust in or below this class (1-4) should trigger management action.

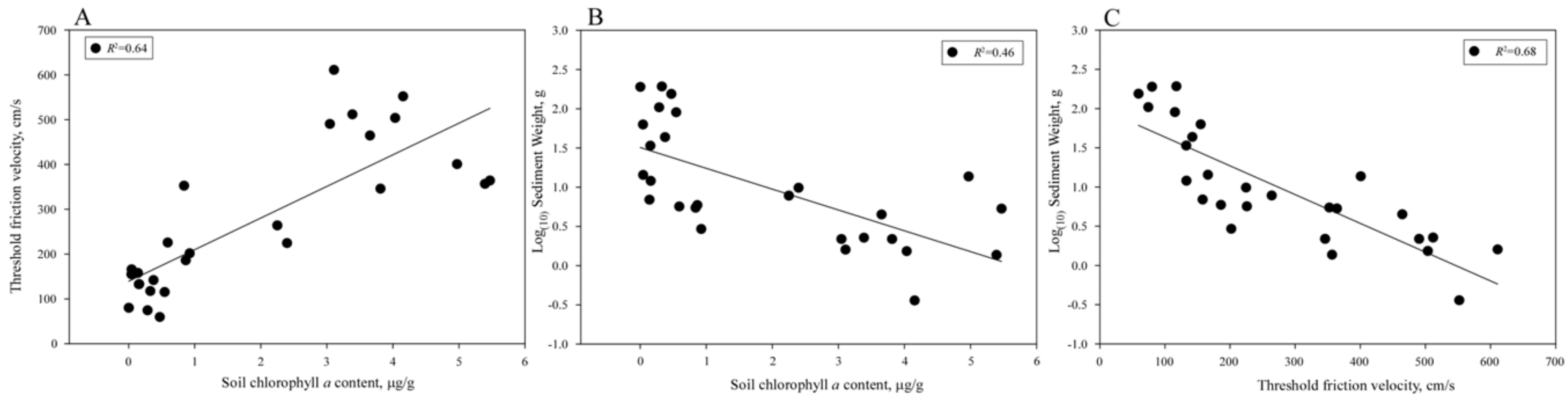


Figure E-12. Chlorophyll content of the biological soil crusts in Mojave Desert soil s is also correlated with both the level of wind it takes to erode soil (TFV) and the amount of soil moved by the wind on undisturbed soils. Therefore, soil darkness indices are expected to work in this regard as well.

Riparian Ecosystems – Hydrologic Function & Vegetation Composition/Structure
We have just begun protocol-development for monitoring structure and function of riparian ecosystems. We have identified our partner in this effort (Mike Scott, USGS-BRD) and have had our initial meetings. We have stratified stream types for which protocols will be developed: small intermittent streams (e.g., Lower Salt Creek in CANY), small perennial streams (e.g., Salt Creek in CANY), small rivers (e.g., Fremont R. in CARE), and large rivers (e.g., Colorado R. in CANY). We have developed a timeline for this project (draft to be completed by March 2004 and protocols field-tested during spring 2004), with the final draft completed by October, 2004. We will be evaluating ground as well as remote sensing techniques for these protocols.

Landscape-Level Monitoring – Climate
We investigated modeling approaches for improved climate monitoring and decided that the network needed models that would estimate spatial and temporal variations in water and energy balances across the landscapes of NCP parks. These models would then enable us to stratify the landscape for monitoring design purposes, predict ecosystem sensitivity to drought conditions, predict variations in soil resistance and resilience to disturbance as a function of moisture availability, and assist us in interpreting temporal and spatial patterns of change in park resources. We issued a contract for this work to USGS-WRD in March 2003 The following products will be developed:

i. Digital spatial coverages gridded at 30-m spatial resolution for all NCPN park units and 270-m spatial resolution for state of Utah, as follows:
   - Monthly mean precipitation
   - Monthly mean potential evapotranspiration
   - Monthly mean snow accumulation
   - Monthly mean snowmelt
   - Monthly mean aridity index

   All monthly coverages will be developed to allow aggregation to user-specified seasonal periods.

ii. FGDC-compliant metadata associated with each of the digital coverages.

iii. Written report (or publication) describing origin / lineage of digital coverages (including modeling methods), underlying assumptions of modeling techniques, and brief description of how coverages should and should not be interpreted and applied.

Landscape-Level Monitoring – Multi-Scale Remote Sensing Methods
We will also be starting the remote sensing module in October, 2003. Due to the large size of most NCP prototype parks and the need to monitor beyond as well as within park boundaries, remote-sensing technologies (defined as any type of aerial sensing) will likely play a role in an integrated, multi-scale monitoring program. We envision the potential application of remote sensing methods at three scales:

i. Broad scale – Adjacent land-use activities (e.g., urbanization, livestock grazing, other agricultural activities) are major concerns to NCP prototype parks as well as parks in the NCPN. Conditions and activities beyond park boundaries can profoundly affect ecosystem conditions within parks through a large variety of mechanisms. Monitoring for changes in land-cover and landscape structure (i.e., spatial configuration of patch types) in landscapes surrounding park lands will require repeated acquisition and analysis of small scale (spatially extensive) imagery. Numerous satellite-based imaging systems are available, with a wide range of products of varying spatial resolution, spectral resolution, sampling frequency, and cost. Some types of imagery are available from as early as the 1970s, allowing retrospective analyses of landscape changes pertinent to current ecosystem conditions within parks. With additional funds requested for FY2003, we will work with a cooperator to evaluate the utility and cost-effectiveness of these small-scale remote-sensing technologies for addressing monitoring needs of NCP prototype parks and NCPN parks. The product of this work will be a report which summarizes the results of these evaluations and makes recommendations concerning feasible, cost-effective strategies for spatially extensive monitoring with remote-sensing technologies.

ii. Intermediate scale – Repeat aerial photography is widely recognized as a valuable tool for monitoring changes in ecosystem and landscape structure. Repeated acquisition of true-color or color-infrared aerial photography (e.g., at 1:12,000 scale) at time intervals coincident with the acquisition of spatially extensive satellite imagery (above) can aid the interpretation of that imagery, and the photography itself can allow for detection of intermediate-scale changes in ecosystem and landscape structure within park boundaries. Methods for acquisition and quantitative analyses of aerial photography are well developed, and we do not anticipate the need for protocol-development work associated with this monitoring method. This type of product will be fully integrated as a component of a multi-scale monitoring approach including small-scale imagery (above) and large-scale imagery (below).

iii. Fine scale – Many resource-management issues faced by parks are associated with networks of interconnected corridors (e.g., roads, trails, riparian zones) and nodes (e.g., trailheads, roadside pullouts, campgrounds). These corridors and nodes are areas where the probabilities of rapid environmental changes are much greater than in the surrounding landscape matrix due to concentrated visitor-use patterns, dynamic natural disturbance regimes, or both (riparian corridors). In many cases, ground-based approaches will be inadequate for monitoring conditions in these areas because of problems with accessibility (river corridors), destructive sampling (damage to intact biological soil crusts by monitoring teams), and high costs (large number of ground monitoring stations required for a distributed network of high-impact zones). With additional funds requested for FY2003, we will work with a cooperator to evaluate the utility and cost-effectiveness of large-scale, high-spatial-resolution remote-sensing technologies (including low-elevation aerial photography) for addressing monitoring needs associated with corridors and nodes. A variety of new high-resolution technologies are availble such as digital aerial videography and low-elevation digital photography. The product of this work will be a report which summarizes the results of these evaluations and makes recommendations concerning feasible, cost-effective strategies for high-frequency monitoring of corridors and nodes susceptible to rapid environmental change. If this work is funded, it will be coordinated with the riparian protocol work described above.

Theme 2: Invasive Exotic Plants

Over the last year the staff developed a framework to organize and depict the relationships among four goals of invasive exotic plant inventory and monitoring in the NCPN parks (Fig. E-13). The framework incorporates a tool (the Alien Plant Ranking System) for categorizing and prioritizing invasive species by degree of threat to the NCPN. Staff efforts have been focused on Prediction, Prevention, and Treatment Effectiveness. Literature pertaining to predicting and monitoring invasions and determining treatment effectiveness has been collected, reviewed (this is an ongoing process), and entered into an EndNote database. This database will be linked to an Access invasive weed database which will be populated with species- and ecosystem-level information about existing and potential weeds in NCPN parks.

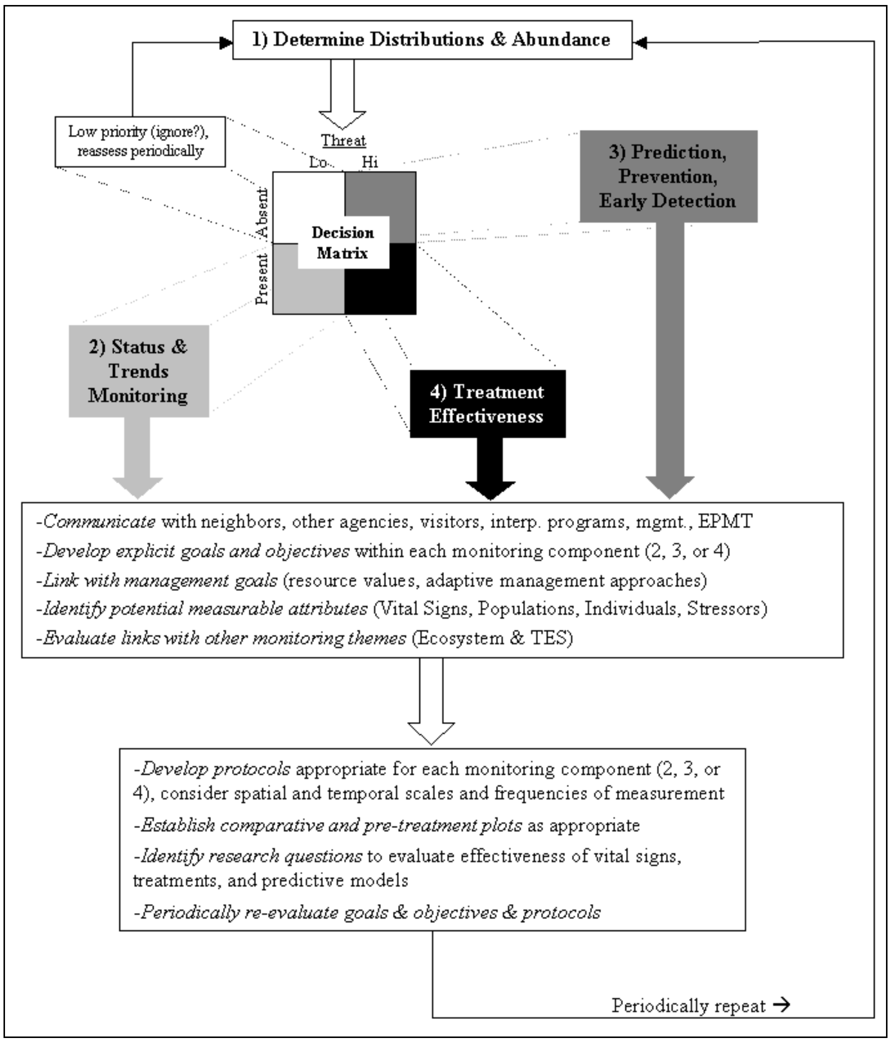


Figure E-13. Draft framework illustrating relationships among various aspects of invasive species detection, treatment, and monitoring.

To assist with NCPN park prevention efforts, USGS staff have completed a guide with best management practices for activities relevant to wildland management (visitor & personnel awareness, fire and grazing management, and infrastructure construction and maintenance). The guide includes pertinent ecological principles to assist managers in modifying and developing additional BMPs. The current version of this guide is presented in Appendix F of the Phase II report, immediately following this appendix.

USGS staff members also have been collaborating with NPS personnel (Ian Torrence, SEUG Vegetation Specialist) in the development of invasive plant treatment effectiveness assessments and protocols. This collaboration is focused around a long-term experiment to evaluate different treatments being used (for control of Russian knapweed within Arches NP) and measurements to indicate successful control and ecosystem recovery.

Theme 3: Species of Concern

To date, work associated with this theme has focused on the development of protocols for monitoring amphibian populations in association with the Department of Interior's Amphibian Research and Monitoring Initiative (ARMI).

ARMI-Related Amphibian Monitoring Protocol-Development Efforts

Amphibians serve as good environmental indicators for several reasons: they occupy terrestrial and aquatic milieus and are sensitive to environmental changes in both; because their skin is permeable to both water- and lipid-soluble compounds, they absorb and are affected by pollutants such as pesticides at very low concentrations. These characteristics make amphibians more sensitive to environmental disturbance than many other organisms in ecosystems, making them excellent candidates as vital signs of ecosystem condition.

There have been two major efforts at developing amphibian monitoring programs recently in response to the apparent decline in amphibian populations around the world, and the realization that we have no quantitative data on population condition for most species. However, both the North American Amphibian Monitoring Program (NAAMP), and the work leading to (Heyer et al. 1994), concentrated their efforts on developing methods for mesic environments, methods that work well for the eastern half of this country, montane areas, and the Pacific Coast region. Very limited work has been done in arid or semi-arid regions, particularly in the development of monitoring protocols to track amphibian populations over time across large landscapes. The ARMI program is attempting to explicitly address these problems in the Mojave and Sonoran Deserts (hot deserts), and the Great Basin and Colorado Plateau (cold deserts).

Some Basic Problems

Two significant problems of monitoring amphibians in arid/semi-arid environments are actually determining if an area is amphibian habitat when conditions are right, the limited period of time that amphibians are active in deserts. These are not significant issues in more mesic environments, and have not been dealt with adequately in monitoring protocols that have been developed in these systems.

Identifying Habitat

Desert toads have been found over 300 m vertical distance above cañon bottom breeding habitat, and over 1 km horizontally from known water sources, so adult habitat encompasses vast areas, but encounters are rare. We have decided to concentrate on surveys of breeding habitat (permanent and ephemeral water bodies) to reduce the workload. However, there is a lack of definitive criteria to identify amphibian habitat if amphibians were not actually found at a particular point Is a depression in a channel amphibian breeding habitat if neither water nor amphibians are present? We have spent considerable time over the past few years trying to determine what characteristics define amphibian breeding habitat on the Colorado Plateau. The extended drought has limited our ability to re-visit sites while they contain water and thus be able to establish which sites are actually amphibian habitat. This will be a primary focus of 2004 efforts.

Even if we are successful in characterizing basin parameters that define breeding habitat, we suspect that most of these features are too small to be detected by remote sensors. This makes it very difficult to be able to select survey areas directly using GIS layers; thus, we have resorted to selecting some larger landscape feature, within which all potential habitat patches will be located and surveyed for amphibians.

Activity Period

Amphibian activity in deserts depends on weather; they may not be seen for months, or, in some cases, years, between adequate rainfall events. On the northern Colorado Plateau there are essentially two separate activity periods: spring breeding and development from late March to mid June, and in late July or early August, following the onset of the monsoon season. To estimate Proportion of (habitat patch) Areas Occupied (PAO, MacKenzie et al. 2002), all visits and repeat visits must be made within the same activity period when the probability of detecting amphibians is the same. This means that areas must be surveyed at least twice within spring or summer periods, reducing the time available to make repeat visits that meet both statistical and biological constraints. Because the monsoons are unpredictable in both time and space, it is very difficult to predict where amphibians might be active in this summer season. For this reason, we have chosen to emphasize the spring activity period, with a possibility of summer surveys in certain areas.

ARMI on the Colorado Plateau

The ARMI program has three levels, [see ARMI (2001)and Graham (2001) for definitions of these levels)]: Base Level, Mid Level and Apex Level monitoring efforts. Both Mid Level and Apex Level areas have been established in Canyonlands National Park, as part of development of amphibian monitoring on the Colorado Plateau.

The Canyonlands Mid-Level Survey Area: Protocol Development

The Colorado Plateau Mid-Level Survey Area (MLSA) was initiated as part of ARMI in 2001, and is focused on Canyonlands National Park and adjacent Glen Canyon NRA and BLM lands to make a coherent Canyonlands MLSA (CANY). NPS Inventory & Monitoring protocol development funds allowed us to extend the field season to explore additional methods and to potentially expand potential mid-level monitoring to include Arches and Capitol Reef National Parks, and Natural Bridges National Monument.

In order to cover large areas of the Colorado Plateau with the available funding, the MLSA was initially divided into smaller units. For the CANY MLSA we used 6th order hydrologic units (HUs).We planned to survey a randomly selected subset of HUs on a rotating four year cycle. Within each HU, at least 20-30 individual habitat patches are required for effective use of PAO, the selected metric for monitoring amphibian populations for each species. Work to date has concentrated on how to select survey areas that 1) allow us to draw inferences about amphibian condition throughout the MLSA (i.e., sites are selected in a probabilistic fashion); 2) can be visited at least twice in a survey period to provide an estimate of detectability needed for PAO estimates; and 3) have some chance of actually containing amphibian habitat.

<u>Second visits and terrain</u>. A major issue, common to all MLSAs with rugged terrain, is that the requirement of multiple visits (at least two) to each potential habitat patch is difficult to accomplish. For example, it may take multiple days of backcountry hiking in areas of limited water to access as few as one or two points; return visits reduce the total number of areas that can be surveyed within the time and funding constraints of the program.

A suggested solution was to conduct the second visits during the same day, or at least the same field session. Our experience indicates this will rarely work because conditions do not typically change rapidly enough to improve detectability of amphibians by the second visit. In more mesic environments, each habitat patch will likely contain water during the first visit, and non-detection of amphibians may be due to true absence, or they were present but not seen or heard. Thus, re-visiting a site within a few hours or days would provide another opportunity to observe amphibians, with roughly the same potential for detection during both visits. In arid environments, however, if the drainage is dry in the morning, it will likely still be dry, in the afternoon, or a couple days later, and any amphibians present would not be detectable because they would be underground. This is a significant issue for cañon country and for rugged mountainous areas, but PAO requires at least two visits to each monitoring site. Possible solutions are to reduce the number of sites, which reduces the accuracy of estimates, or to increase the staff to allow coverage of more areas within the activity period.

Four different survey methods have been used in the quest to find the most efficient and effective approach:

- 2001: Entire Hydrologic Units (HU) surveyed
- 2002: 1km^2 plots within HU surveyed
- 2002: random points in drainages
- 2003: 500m segments of drainages

<u>Entire HUs</u>. In 2001, we delineated 32 6th order HUs centered on Canyonlands National Park to make up the CANY MLSA. We planned to survey at least three entire HUs each year, at least twice, and to re-visit individual HUs on a four-year rotation. Initially we decided to select three

primary and two secondary HUs to be surveyed each year; the secondary HUs were to be surveyed only if there was time after fully covering the primary HUs each year. In 2001, two of the three primary HUs, and ~70% of the third primary HU were surveyed once. Both secondary HUs were completely surveyed one time. These HUs, which range between 4,700ha and 15,650ha, contain remote and sometimes inaccessible terrain, making it impossible to effectively survey these areas at least twice during a season.

<u>One square kilometer plots</u>. In 2002, two survey methods were tested. First, randomly selected 1 km^2 plots, totaling approximately 20 percent of each HU area, within the three primary HUs in the 2001 rotation were surveyed in their entirety. These locations were often remote, making travel time excessive and return visits infeasible. In fact, the logistical problems of reaching these cells were essentially the same as surveying the entire HU.

<u>Random points in drainages</u>. A second survey method was devised to reduce the logistical difficulties of surveying areas, and tried in late summer 2002: random points were selected from the hydrography GIS layer, which are essentially the solid and dotted blue lines of a topographic map. Once at a point, technicians would flip a coin to determine direction, and then walk until habitat was found. This habitat patch was surveyed for amphibians, and habitat characteristics data were collected. This "blue line" selection process was tried only in Arches NP in 2002.

<u>500 m segments in drainages</u>. In 2003, the "blue line approach" was modified and tried in the CANY MLSA, as well as in Arches NP and Natural Bridges NM. Random 500 m segments were selected from 10 percent of the total number of 500 m segments in the MLSA. Since surveying occurred only along drainages, technicians were likely to find more habitat patches in 500 m of drainage per unit search time than searching entire HUs or 1 km^2 cells. This method is more logistically viable from the standpoint of planning and executing surveys, since we can expect that it will be possible to re-visit the segments and habitat patches within them in a timely fashion.

Despite the advantages of using 500 m segments, there are some limitations to this method. Approximately 22% of the segments surveyed in 2003 contained no potential amphibian breeding habitat based on criteria we have developed thus far. This method of selecting survey units explicitly excludes some amphibian breeding habitat and activity: the summer monsoon activity period and breeding cycle is ignored, and any breeding habitat outside of drainages are not included in the universe of potential habitat to be surveyed. Thus, potholes (e.g., rock pools outside of drainages), some stock ponds, swales in undulating topography, and wet meadow pools could not be selected for survey. As a result, inference about amphibian population condition could only be made for drainage populations.

The range of inference has also been limited in other ARMI MLSA studies. For example, in Olympic National Park, only mapped ponds on slopes of less than 30% are included in the selection process. It might be possible to conduct research into the connectivity between drainage- and upland-breeding populations in Colorado Plateau areas, and thus establish whether conditions of drainage-breeding populations reflect conditions of other populations, but this would be a directed research effort, and would entail additional funding. At this time, we should concentrate on establishing a viable monitoring program, and if there are trends that raise some concern, we can pursue the relationship with populations that are not currently being monitored.

Alternative methods to select survey points. Inventory the entire MLSA, identifying all available habitat patches. The set of habitat patches then becomes the universe from which monitoring locations will be drawn. This has a large initial cost, but a major advantage is that all potential habitat patches are available for monitoring, which means that both upland and drainage populations will be monitored, and inference can be made throughout the MLSA. In addition, once potential habitat has been identified, surveys can be more efficient because there will be less search time spent trying to find the habitat; this time can be spent *at* the sites searching for amphibians.

It may be possible to provide adequate data to a GIS that will allow for elimination of portions of a MLSA with no chance of being habitat. For example, evaluation of low-elevation, high-resolution aerial photography for habitat features, and subsequent training of a GIS to recognize aggregates of these features that are likely to be amphibian habitat may provide a relatively accurate universe from which to select monitoring locations.Refine the 500 m segment method of 2003 by providing subjective criteria to stratify the MLSA into areas likely to contain amphibian habitat and areas very unlikely to contain appropriate habitat. For example, use DEM and geology layers to identify large areas with very little slope and no bedrock exposure that are very unlikely to contain amphibian breeding habitat. These areas could be weighted such that the GIS selects 10% (or some other low percentage) of this poor quality habitat to be surveyed. This approach may eliminate some potential habitat, but will direct most effort to areas that have a higher probability of containing amphibian habitat and thus may be more cost effective.

Apex-Level Monitoring at Canyonlands NP

Two Apex Level Monitoring Areas (ALMAs) have been designated in Canyonlands NP in conjunction with ARMI and other research efforts. These are Horseshoe Canyon, and the middle section of Salt Creek within the park.

At Horseshoe Canyon, visual encounter surveys (VES) are conducted weekly (with some gaps), from the onset of toad activity (usually late March) until cessation of toad activity in late September or early October. Numbers of individual adult, yearling and metamorph toads are counted and assigned to size classes, and numbers of eggs and tadpoles estimated, and tadpoles are assigned to size classes. Some surveys were done in 1990 and 1991, work commenced again in 1999, with continuous records since then. *Bufo woodhousii, B. punctatus, Spea intermontana*, and possibly *S. bombifrons* have all been documented in these surveys.

Work in Salt Creek Canyon was started in 2000, and is mostly being conducted in conjunction with studies of amphibian and invertebrate dynamics in relation to the 4WD road in the canyon. In 1998, most of the road was closed to vehicles. In 2000, a total of 16 study sites were established: three in the no road section above the closed road, 10 in the closed road segment, and three in the lower portion of the road still open to vehicles. Amphibian work consists of 16 pitfall traps at each site, run for four nights, and afternoon and evening VES on three transects along the canyon bottom at each site. Fourteen of the 16 sites have been surveyed at least once over the past four years. Data are available for April and June-October 2000, and May-September for 2001-2003. This work is currently funded entirely by USGS, Canyonlands NP, and Earthwatch Institute; none of these sources is projected to continue beyond 2005, thus if this ALMA is to remain active, ARMI and/or additional NPS funding will be needed. *Bufo woodhousii, B. punctatus, Spea intermontana*, possibly *S. bombifrons* and *S. multiplicata,* and *Ambystoma tigrinum* have been documented in Salt Creek surveys.

Literature Cited

Amphibian Research and Monitoring Initiative Task Force (ARMI). 2001. *Conceptual design and implementation guidance for the Amphibian Research and Monitoring Initiative*. U.S. Geological Survey, Reston, VA. 60 pp.

Barger, N. 2003. *Biogeochemical cycles and nitrogen dynamics of biological soil crusts in a semi-arid environment*. Unpublished dissertation, Colorado State University.

Belnap, J., and D. A. Gillette. 1997. Disturbance of biological soil crusts: Impacts on potential wind erodibility of sandy desert soils in southeastern Utah. *Land Degradation and Development* 8: 355-362.

Belnap, J., and D. A. Gillette. 1998. Vulnerability of desert biological crusts to wind erosion: the influences of crust development, soil texture, and disturbance. *Journal of Arid Environments* 39: 133-142.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. *The American Naturalist* 148: 1016-1037.

Evans, R. D., and J. R. Ehleringer. 1993. A break in the nitrogen cycle in aridlands? Evidence from $\delta^{15}N$ of soils. *Oecologia* 94: 314-317.

Graham, T.B. 2001. *Amphibian Research and Monitoring Initiative – Canyonlands monitoring area: Protocol-development efforts, 2001*. U.S. Geological Survey, Moab, UT. 16 pp.

Herrick, J. E., W. G. Whitford, and M. Walton. 2001. Field soil aggregate stability kit for soil quality and rangeland health evaluations. *Catena* 44: 27-35.

Heyer, W.R., M.A. Donnelly, R.W. McDiarmid, L.-A.C. Hayet, and M.S. Foster. 1994. *Measuring and monitoring biological diversity: Standard methods for amphibians*. Smithsonian Institute Press, Washington, D.C. 364 pp.

Jenny, H. 1941. *Factors of soil formation: a system of quantitative pedology*. McGraw-Hill, New York.

Jenny, H. 1980. *The soil resource: origin and behavior*. Springer-Verlag, New York.

MacKenzie, D.I., J.D. Nichols, G.B. Lachman, S. Droege, J.A. Royle, and C.A. Langtimm. 2002. Estimating site occupancy when detection probabilities are less than one. *Ecology* 83:2248-2255.

McKenna-Neuman, C., C. D. Maxwell, et al. 1996. Wind transport of sand surfaces crusted with photoautotrophic microorganisms. *Catena* 27: 229-247.

Whitford, W. G. 2002. *Ecology of desert systems*. Academic Press, San Diego.

Appendix F. NCPN Invasive Plant Prevention Guidelines and Best Management Principles

Prepared by:

Richard Alward, USGS-BRD

17 September 2003 WORKING DRAFT

Acknowledgments

This guide is a compilation of several available lists and recommendations; however, it draws most heavily from Janet Clark's chapter on "Prevention" in the Center for Invasive Plant Management's ***Ecological Invasive Plant Management Textbook****. (Her chapter was largely adapted from the USDA Forest Service "Guide to Noxious Weed Prevention Practices.") Other sources included the Colorado Integrated Weed Management Plan, Partner's Against Weeds (PAWs) Action Plan for the Bureau of Land Management:* ***Integrated Weed Management Guidelines****, the USFS Lolo National Forest Plan* ***Noxious Weed Mgt. Amendment****, and the CIPM's* ***Guidelines for Coordinated Management of Noxious Weeds****. Additional sources are listed in Section V. Thoughtful comments on earlier drafts were provided by Mark Miller (USGS), Beth Newingham (USGS), Tamera Minnick (Mesa State College), Denise Louie (NPS) and Tamara Naumann (NPS).*

I. Introduction

Invasive exotic plants are a concern to wildland managers throughout the world. Such plants are a threat to biodiversity (only habitat destruction is a greater threat) and interfere with management goals. Furthermore, left uncontrolled, invasive exotic plants are an impossible hurdle for the manager attempting to adhere to the National Park Service mission "to conserve the scenery and the natural and historic objects and the wildlife therein, and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for future generations." An **exotic** (or alien) plant is a species that is not native in a particular geographic location, and whose arrival in this new location came about through the intentional or unintentional activities of humans. An **invasive exotic plant** is a species that can subsequently expand its population (and distributional range) and displace native species, without further human intervention (from Usher 1991). The negative consequences of invasive exotic plants are numerous. Invasive exotic plants can alter (1) community species composition (to the point of displacing native species and becoming the new dominant species), (2) natural disturbance regimes (including those of fire, wind and water erosion, and grazing), (3) the height of water tables and surface flow in ephemeral streams, (4) the abundance and distribution of soil nutrients, as well as (5) the primary production of natural systems, as compared to similar, non-invaded systems. The actual ecological effects of these plants vary depending upon the characteristics of the invader itself as well as attributes of the invaded ecosystem.

By far, the most cost-effective strategy for minimizing impacts of invasive exotic plants to natural ecosystems is to *prevent* their initial establishment and spread. The purpose of this document is to provide on-the-ground park staff with information and guidance that may be used to aid the development of a proactive, park-based invasive-plant prevention program. Following the introduction, the document is organized in five sections. The first of these presents background information intended to place preventative practices in the context of an *overall framework for invasive plant monitoring*. The second section provides a brief overview of *ecological principles* pertinent to the prevention and management of exotic plant invasions. The third section focuses on interpretation, education, signage, and other activities that will help prevent exotic plant invasions by *increasing human awareness*. The fourth section presents a suite of *best management practices* intended to ensure that NPS management activities do not facilitate the establishment and spread of invasive exotic species. Finally, the last section provides park staff with additional resource materials (e.g., invasive plant websites, sample brochures) that may be useful in the development of invasive-plant prevention programs.

Background -- Framework for Invasive Plant Monitoring

In June 2002, NPS land managers, and others, participated in a workshop to identify common goals, objectives, and guidelines for invasive plant assessment, inventory, and monitoring. The threat of invasive exotic plants is one of the three emphasis areas of the NPS Natural Resource Challenge. This workshop was due, in part, to the agreed importance of this emphasis among NPS managers and recognition that common approaches would best facilitate responding to the challenge. The participants evaluated numerous inventory & monitoring guidelines developed by government agencies and university researchers and made a summary of the workshop's efforts available online at www.nature.nps.gov/im/monitor.

Effective management of invasive exotic plants requires clearly stated goals from which can be developed measurable objectives. The workshop participants emphasized that the goals of invasive exotic plant management went beyond just treating and killing invasive populations. The goals of all NPS managers should include "protecting and/or restoring the function, structure, and composition of the systems NPS is entrusted to manage." To this end, the workshop participants identified the following four common goals for invasive exotic plant management:

Goals for Invasive Exotic Plant Inventory & Monitoring

- Determine the distribution and abundance of known plant species within and around parks. Assess which plants are present and which have a high potential to be invasive.
- Determine the status and trends of plant invasions over time and space and develop predictive capabilities to better guide future monitoring and management efforts.
- Prevent, predict, detect, and eradicate new alien plant invasions
- Evaluate the effects of management actions on targeted plant species and the ecosystems that they have invaded and determine whether strategic goals have been accomplished.

In January 2003, the NCPN Technical Committee agreed that the above four goals should be adopted for invasive exotic plant inventory and monitoring efforts within the network parks and monuments. The NCPN Invasive Exotic Plant Monitoring Framework (Fig. F-1) serves to graphically and logically organize these four goals and to assist in identifying appropriate management objectives and activities based on the threat that exotic species place on natural resources. The first goal of a monitoring program is to describe the distributions and abundance of the species of concern. This is achieved through a thorough inventory and mapping program. In recognition that managers' (and the network's) resources are limited, actual monitoring efforts will need to be prioritized. These priorities should recognize both the threats imposed by the invasive exotic species as well as the value of the park's natural resources that are being threatened. Thus, the next step is to evaluate the proximity and severity of a potential threat through the use of a combination of expert knowledge and a ranking tool (such as the Alien Plant Ranking System, available through the Southwest Exotic Plant Information Clearinghouse, SWEPIC). The 2×2 grid in the center of Fig. F-1 is a simplification of the output of the results of ranking species identified in Goal 1.

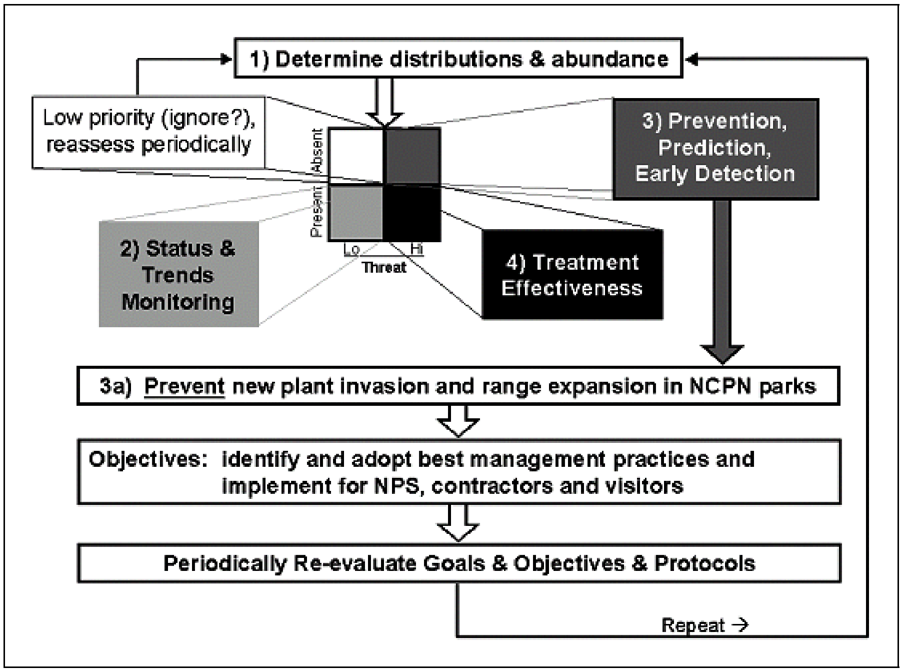


Figure F-1. The NCPN Invasive Exotic Plant Monitoring Framework, emphasizing Goal 3a.

Based on the ranking output, exotic plant species known to have invasive characteristics when established in the region or site of concern (e.g., plants that can displace intact native vegetation or otherwise pose a significant threat to valuable natural resources) and identified as currently absent from a park or site, would direct the manager to adopt appropriate objectives and protocols that follow from Goal 3 (Prevent, predict, detect, and eradicate new invasions).

By far, the most effective, economical, and ecologically sound method of managing invasive exotic plants is to prevent their invasion in the first place. Often landowners and land managers pour resources into fighting weed infestations after they are firmly established. By that stage, ongoing control is prohibitively expensive and eradication is probably not an option (Fig. F-2). Resources might be more efficiently used in proactive weed management activities. Of course, proactive weed management relies on management of existing infestations, but the strongest focus should be on prevention or early detection of new invasions.

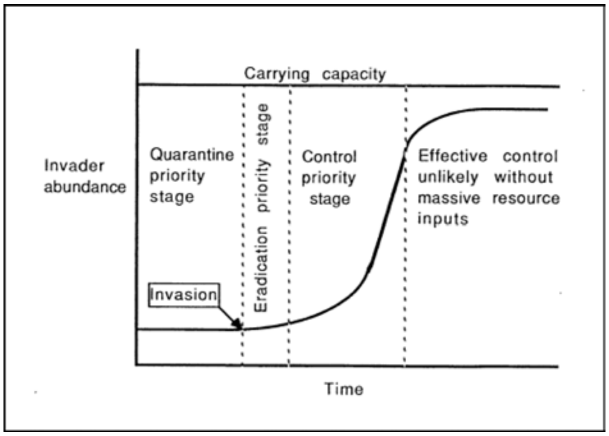


Figure F-2. Phases of exotic plant invasion and priorities for action at each stage. Tremendous resources are required, and control unlikely, if a manager waits too long to act. However, significant resources are also required to detect small populations typical of the early invasion phase. By far, prevention is the least costly method (from Hiebert et al. 2002, Hobbs 1995).

Over 300 exotic plant species can either be found currently in NCPN parks and monuments, or are an imminent threat to the region either because they are found in the region, but outside of parks, or are included on state noxious weed lists even though they currently have not been found in the region (see Additional Materials and Information section). From this long, and continually expanding list, thirty-seven invasive exotic species have been identified by park staff as particular concerns due to current rates of increase, difficulty of control, and the significance of resources impacted (Table F-1).

Table F-1. Invasive exotic plant species of greatest concern to NCPN parks and monuments.*

Trees and shrubs	**Perennial forbs**	**Annual / monocarpic forbs**
Ailanthus altissima (Tree-of-Heaven)	*Cardaria draba* (Whitetop)	*Arctium minus* (Common burdock)
Elaeagnus angustifolia (Russian olive)	*Centaurea diffusa* (Diffuse knapweed)	*Carduus nutans* (Musk thistle)
Tamarix ramosissima (Salt cedar, Tamarisk)	*Centaurea maculosa* (Spotted knapweed)	*Centaurea solstitialis* (Yellow starthistle)
Ulmus pumila (Siberian/Chinese elm)	*Centaurea repens* (Russian knapweed)	*Cirsium vulgare* (Bull thistle)
Perennial grasses	*Centaurea squarrosa* (Squarrose knapweed)	*Cynoglossum officinale* (Houndstongue)
Bromus inermis (Smooth brome)	*Cirsium arvense* (Canada thistle)	*Halogeton glomeratus* (Halogeton)
Dactylis glomerata (Orchardgrass)	*Convolvulus arvensis* (Field bindweed)	*Hyoscyamus niger* (Black henbane)
Festuca arundinacea (Tall fescue)	*Euphorbia esula* (Leafy spurge)	*Melilotus alba* (White sweet clover)
Phleum pratense (Timothy)	*Lepidium latifolium* (Perennial pepperweed)	*Melilotus officinalis* (Yellow sweet clover)
Poa pratensis (Kentucky bluegrass)	*Linaria genistifolia* ssp. *dalmatica* (Dalmatian toadflax)	*Onopordum acanthium* (Scotch thistle)
Annual grasses	*Linaria vulgaris* (Yellow toadflax)	*Salsola iberica* (Russian Thistle; Tumbleweed)
Bromus rigidus (Ripgut brome)	*Marrubium vulgare* (White horehound)	*Tragopogon dubuis* (Goatsbeard; Salsify)
Bromus tectorum (Cheatgrass)	*Sonchus arvensis* (Marsh sowthistle)	*Verbascum thapsus* (Common mullein)

*Adapted from Table 19, p. 59, in Evenden, et al. 2002.

Elements of a *proactive* invasive exotic prevention plan include: limiting exotic plant seeds into an area; early detection and eradication of small patches of exotics; proper management of vegetation along roadside, trails, and waterways; land management practices that build and maintain healthy communities of native and desirable plants that compete well against exotics; careful monitoring of high-risk areas; and annual evaluations of the effectiveness of the prevention plan so appropriate adaptations can be implemented the following year.

Successful prevention programs for managed wildlands such as those encompassed by the NCPN parks and monuments require (1) efforts to increase awareness of this threat among visitors, contractors, and NPS personnel and (2) efforts on the part of managers to identify and implement a program of Best Management Practices. This guide has been produced to assist managers and resource specialists in these efforts and it is organized around the varying objectives that may be more or less appropriate for success in these different efforts.

The remaining four sections in this guide were developed to assist managers and resource specialists in their efforts towards meeting Goal 3 by increasing the likelihood that:

Visitor, contractor, and NPS personnel activities do NOT enhance opportunities for the spread of invasive exotic plants in and around NCPN parks and monuments.

The next section is a brief summary of the ecological principles that inform our current understanding of the processes that underlie exotic plant invasions. In short, plant invasions are just a special, and worrisome, aspect of plant succession. Likewise, effective restoration and repair of ecosystems following removal of invasive exotics should exploit the processes underlying natural plant succession. The goal with presenting this summary is to assist managers in evaluating existing Best Management Practices and/or developing additional ones for the particular situation that the manager is trying to remedy. Even if this summary serves merely to help a busy manager more clearly communicate with biological specialists, the goal will have been met.

Section III includes suggestions for interpretation, education, signage, and other activities that will help to increase awareness of means for preventing exotic plant invasions among visitors, contractors, and NPS personnel. In some cases extensive, long-term, education efforts may be necessary (e.g., to encourage visitors to view NPS lands as dynamic, ever-changing ecosystems, as opposed to being static, unchanging entities). In other cases, simply providing an easy means for the concerned visitor to dispose of seeds found in her socks may greatly reduce the distribution of exotic invasive plants into backcountry campsites.

Section IV presents Best Management Practices that are appropriate for different activities and divisions with NPS. These lists should be made available to the appropriate supervisors and specialists, or the people who are responsible for performing these functions, including the maintenance supervisors, botanists, fire specialists, and biologists. These lists of practices should be considered for all projects, during the planning stages if at all possible, however it is unlikely that all practices will be implemented in every project.

Section V includes additional materials that managers and resource specialists may find useful: citations for the literature consulted to develop this guide, lists of exotic plants threatening the NCPN, links to useful exotic plant internet resources, as well as examples of relevant programs, standards, contract language, brochures and signs.

II. General Ecological Principles Pertinent to Invasive Plant Prevention

This section is a brief introduction to the pertinent ecological principles behind exotic plant invasions. An understanding of the mechanisms of invasions can assist land managers to evaluate Best Management Practices [BMPs] and understand how BMPs can reduce the rates of invasions. This knowledge can be used to guide development of site- or activity-specific BMPs that are not explicitly addressed in the remainder of this document. Busy managers may want to use this section as an aid in communicating with biological specialists.

Natural biological communities and ecosystems are dynamic. That is, they do not reach one state and remain there. Plant community composition may change from year to year, even in communities that are not invaded. It takes only a few measurements to be able to detect seasonal and annual changes in plant species abundance, growth rates, and flowering of different species, and the number of species in an area. This perspective (the dynamic nature of ecological systems) encourages the manager to recognize that change is to be expected and that the manager should strive to direct and manage change rather than prevent it. Random or fluctuating changes in species abundance are termed *vegetation change*. These changes often track variations in annual precipitation, fires, tree falls, herbivore population cycles, etc. In general, the dominant species remain dominant and rare species remain rare in the face of these random changes.

In contrast, *succession* is the directional change in plant species composition over time that extends over many growing seasons. During succession, species that were prevalent early become less abundant and species that initially were rare or absent become dominants in the community. This directional change is driven by processes that make the environment less suitable for the dominant species and more favorable for other species. These processes may be geophysical or biological.

It is often useful to distinguish between two types of succession. *Allogenic succession* is the result of changing external geophysical conditions. (e.g., disturbance frequency, climate change, erosion, and silt or salt accumulation). If the climate in an area becomes warmer and drier, then the plants that dominate the community increasingly will be those that can best tolerate these conditions. The plants that were dominants when the climate was cooler and wetter will decrease in abundance. It is important to recognize allogenic processes because there may be little a manager can do but assist the change in the plant community in a desired direction. *Autogenic succession* occurs as the result of biological processes modifying conditions and resources. Some examples are plants that grow taller and cast shade on other plants, or plants that release chemicals into the soil that inhibit growth of other species, or plants that produce many roots near the surface and help stabilize soils, allowing for other species' seeds to germinate.

New successional processes are initiated when events result in increased availability of resources (e.g., nutrients, water, space) for a vegetation community. Succession initiating events may be classified as either disturbances or stressors. A *disturbance* is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability [i.e., space] or the physical environment (White and Pickett 1985) and are of a magnitude and frequency within the evolutionary history of the ecosystem (e.g., monsoons, drought, fire). For comparison, a *stressor* is an anthropogenically-induced event that is outside the range of disturbances naturally experienced by the ecosystem (Whitford 2002).

A disturbance or stressor may result in increased resource availability by either an increase in supply or by a decrease in consumption. In dry and/or low nutrient ecosystems, an unusually wet season (disturbance) or nutrient additions by way of pollution or fertilizer application (stressor) results in an increase in supply of important resources. For example, a wet season may provide more water than the naturally sparse vegetation can consume. This excess water can then be exploited by exotic species to increase in abundance and become a larger component of the community. On the other hand, a drought (disturbance) or herbicide application (stressor) may kill plants. This results in an increase in the availability of soil nutrients and space due to a decline in the rate of consumption of these resources.

Typically, land management activities may cause multiple disturbances and/or stresses. For example, management may construct a ditch in order to divert runoff water away from roads or buildings. The creation of the ditch is a stressor that involved scraping off plants and soil, creating new bare soil (space) that may be colonized by native or exotic species. Additionally, the water that is redirected by the ditch accumulates elsewhere resulting in an abundance of water somewhere else in the ecosystem.

Exotic plant invasions are just a special, and worrisome, case of plant succession. A species that is absent, or uncommon, is introduced into a plant community, a small number of individuals establish a foothold, and then, through combinations of allogenic and/or autogenic processes, it becomes a significant (if not dominant) member of the community. For example, some invasive plants release chemicals that inhibit growth in other plants (Russian knapweed), some result in changes in fire regimes (Downy brome or cheatgrass), and some facilitate accumulations of salts near the soil surface (Tamarisk). The natural processes that allow exotic, invasive plants to become dominant members of vegetation communities, that is, the processes of succession, are relatively few and may be exploited by land managers to modify and direct succession into either desirable or undesirable directions.

Plant succession is a function of three controlling mechanisms: species availability, species performance, and resource availability (Fig. F-3). These three controls, the processes that contribute to them, and the factors that modify the processes, are summarized in Figure F-3 and are described in greater detail below.

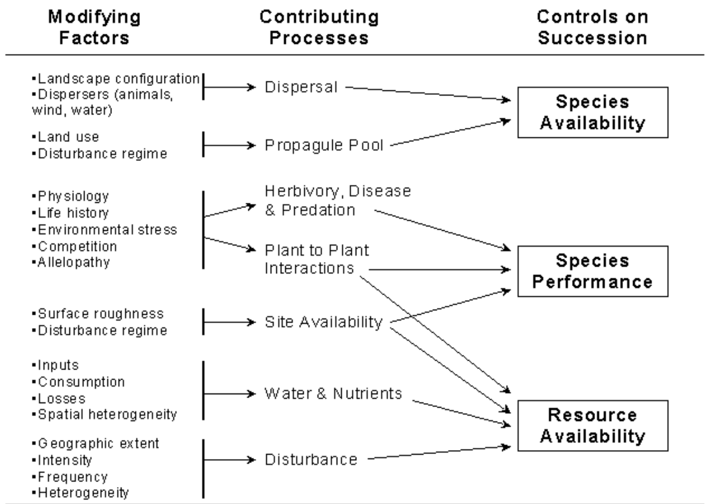


Figure F-3. Diagrammatic representation of the controls on succession, the contributing processes, and modifying factors that can shift processes to favor exotic plant invasions (adapted from Pickett et al. 1987 and Whisenant 1999).

Species Availability

Species availability is one of the three controls on succession (Fig. F-3). If an exotic plant species is not present within the region it cannot become established in a local community. However, an exotic species does not have to be established nearby in order to be of concern. Some plant species can move large distances quite rapidly, especially if dispersal is aided by humans or other animals. For instance, even if the species is nearby, there are processes that may increase or decrease the likelihood that it will disperse into the community of concern to the manager. These processes include dispersal and the dynamics of the propagule pool (Fig. F-3).

Dispersal encompasses the rates and distances and mechanisms that plants use to ensure that some seeds find suitable growing sites. Having some information about the speed and distances that species can disperse will assist managers in knowing what new exotics to be on the lookout for and whether or not particular sites are vulnerable to invasion. Mechanisms include wind and water dispersal of seeds as well as animal dispersal. For example, plants with seeds that can cling to clothing or fur have greater potential to disperse greater distances than those that require going through the digestive track of an uncommon mouse. If a disperser is not available (i.e., that mouse species is absent) then dispersal will not take place, unless a substitute dispersal process is available. Landscape connections or barriers will also modify dispersal. A large expanse of desert may inhibit a wind-dispersed species from arriving at a new site that is otherwise suitable for its growth. A river or large expanse of bare rock may prevent the migration of an animal disperser, and likewise prevent the dispersal of the plant.

A *propagule* is any part of a plant that can regenerate an adult plant. Typically, this means seeds. However, many plants can regenerate from parts of stems (prickly pear cactus and tamarisk) and roots (Russian knapweed). This is a process similar to the propagation of house plants from cuttings. The *propagule pool* is important to consider in succession because it may differ from the vegetation that you see at the time, and may be damaged by disturbance. For instance, it frequently happens that seeds disperse into an area, but conditions are not right for it to germinate. A short-lived seed will die. However, if the seed is long-lived, it may stay in the soil, and germinate one or more years from when it was initially dispersed. In the case of cheatgrass, seeds are produced multiple times per year, and a large number of seeds are stored in the soil (the seed bank). They can germinate under many different conditions. Thus, even if you mow a field after early spring, there are many seeds still present in the soil which can germinate. Even if you use controlled burning to destroy plants, the seed bank is still there.

Species Performance

How well a species performs (grows, competes with other plants, reproduces, etc) in a new site is the second control on succession in Fig. F-3. Even if an exotic species is introduced into a new community, it might not become established and increase in abundance. Whether the exotic plant becomes a member of the community depends on how the new species responds to the numerous processes that can influence its performance. The existence, within the new area of herbivores, diseases, seed predators, other plant species that compete for the same resources, and suitable growing sites all contribute to the success of the exotic.

Site availability is a crucial consideration; if there are no suitable sites for a seed to germinate and an adult plant to grow, then none of the other factors and processes will have an opportunity to act. For instance, soil surface roughness will influence whether or not there are cracks or low spots for a seed to settle. These types of sites are also more likely to accumulate nutrients and water that will promote seed germination. If a site is repeatedly subjected to physical disturbance, say every year, then perennial plants may never become established and the site will be dominated by annuals. The rate at which new sites become available is the one process over which the land manager has the most control. Best management practices that minimize vegetation removal and promote soil stabilization and revegetation efforts will help to minimize the area available for exotic plants to gain a foothold.

Interactions with the existing flora and fauna are also important contributing processes. The presence of *herbivores*, *diseases* and strongly *competitive plants* may reduce performance levels. Being able to escape these processes can greatly contribute to an exotic plant's ability to become established. For example, an exotic plant's physiology may allow it to grow, mature, and set seed during the winter months in the desert. If insect herbivores or disease organisms are active only during the spring and summer, then such an introduced plant may be able to increase more rapidly than an exotic plant whose growth period overlaps that of disease organisms. Additionally, some plant species produce chemicals that make them distasteful to herbivores, or secrete chemicals that inhibit growth of potential competitors (allelopathy). Such a species will have an advantage and is more likely to become an established part of the vegetation community more quickly than a plant that is vulnerable to herbivory or is a weak competitor for important resources. This is one of the reasons invasives do so well in their new environments - natural herbivores, diseases and competitors that keep populations in check in the native habitat are often not transferred with the plant.

Resource Availability

Whether or not important resources (nutrients, water, space) are available, is the third and final control on succession in Fig. F-3. If resources are being efficiently consumed and cycled through an ecosystem, it decreases the likelihood that an exotic plant will be able to invade such a system. When resource availability increases, and the established vegetation community is not able to fully use these new resources, then these resources are available for an exotic plant to exploit.

Most native plant species in arid and semiarid regions have low requirements for *water and nutrients*. Even a slight increase in these resources may result in an excess in the community. Such an increase could come about because plants are consuming less (perhaps because they've been removed) or because resources are being supplied at a greater rate (for example, due to increased precipitation, nitrogen-based pollution, erosion from an upslope site that was disturbed, etc).

Site availability, or space, is also an important resource. Although there appear to be many spaces between plants in arid environments, it is often the case that the roots of these plants overlap, and thus there really are not adequate sites for a new plant to become established. Plant removal, whether by road construction, ditch maintenance, or social trails all increase site availability and thus facilitate invasions by exotic plants.

Disturbance is, of course, a natural part of all vegetation communities. For example, tree falls, floods, rockslides, fires, gopher mounds, and bison wallows are all important processes that allow young plants an opportunity to become established. Different sizes of disturbances tend to happen naturally at predictable time scales. For instance, a large disturbance, such as a forest fire that covers many acres may only affect communities once every 100 to 300 years, while the death of an individual tree may occur every year within a 10 ha plot. Changes in these natural disturbance patterns can result in changes in the vegetation community. For instance, a decrease in the frequency and intensity of flooding allows plants such as tamarisk to colonize sandbars in rivers. Long, continuous clearings of vegetation (such as happens with road maintenance) become conduits for exotic plants to become established throughout a park.

Conclusion

Disturbance and succession are a natural part of community processes. However, when the disturbance regime is changed, opening new resources for plants, invasions can occur, leading to drastic changes in successional processes. However, following BMPs may allow managers to control some of the processes that contribute to exotic plant invasions. Being aware of plants that are poised to move into an area, as well as some of their basic requirements for germination and growth, can help to make invasive control preemptive rather than a series of dealing with large-scale problems.

III. Increasing Invasive Exotic Plant Awareness

Increasing visitor and personnel awareness of the threats and consequences of exotic plant invasions is an important step in protecting wild land ecosystems from these threats. For example, efforts at increasing visitor and personnel awareness of the existence, appearance, function and importance of biological soil crusts have paid off in reduced damage to these fragile organisms. Efforts at increasing awareness of the problems associated with exotic plants can be considered an investment that will be paid of in reduced costs later. The effort required to remove exotic plants and restore invaded ecosystems is many times the effort of preventing the problem initially (refer to Fig. 2 in Section I). Below are some suggestions; adapting from the "Don't Bust the Crust" program would be a good guide for parks and monuments within the Northern Colorado Plateau Network. Other awareness programs, such as the Air Quality Public Awareness Program at the Black Canyon of the Gunnison River NP will also offer good guidelines.

One objective of a Public Awareness Program is to assist visitors and personnel in identifying and increasing their awareness of exotic plant species that are threatening to invade lands under management.

- Awareness efforts can include the following approaches (see below for more detailed recommendations and see Section V for links with more suggestions):
    - Brochures & pamphlets
    - Signs
    - Interpretive posters
    - Weed & seed disposal containers at trailheads & visitor centers
    - Tours for visitors and volunteers
    - On-site photo exhibits of before & after weed removal efforts

A second objective is to avoid moving weed seeds or propagules into the backcountry, and to prevent new weed infestations and the spread of existing weeds and to avoid or remove sources of weed seed and propagules, awareness programs should include instructions and advice for the following actions that can be taken by visitors and personnel.

- Inspect and clean clothing, boots, packs, tents, bikes, and other equipment before taking going into a new area. Remove all seeds and plant material. Deposit in garbage cans.
- Ask about what the problem weeds look like and where they are problems.
- Do not leave campgrounds except via constructed trails and roads.
- Volunteer to help with trailhead exotic plant removal efforts.
- Inspect and clean motorized and mechanized trail vehicles of weeds and their seeds.
- Keep dogs and other pets free of weed seeds, especially if pets are allowed at campgrounds.
- Avoid picking unidentified "wildflowers" and discarding them along trails or roadways.
- Avoid dumping aquarium water or aquatic plants into local waters. Many plants for water gardens and aquaria are highly invasive.
- Support the development and distribution of weed-free or weed-seed-free feed, hay, straw, and mulch.
- Brochures and posters should describe efforts at exotic plant removals and the annual costs for these efforts (to be compared to the costs for prevention).

<u>BMPs that Serve to Increase Invasive Exotic Plant Awareness</u>

Objective: Identify and increase awareness of exotic plant species that are threatening to invade lands under management.

- Contact appropriate personnel in state and county weed agencies on a regular basis to keep informed on the latest threats in the area and to update these guidelines with the current Best Practices for prevention.
- Communicate regularly with neighboring landowners and agencies to stay apprised of invasive threats and to coordinate prevention activities.

Objective: Improve effectiveness of prevention practices through weed awareness and education.

- Educate personnel and visitors in weed identification, biology, impacts, and effective prevention measures.
- Provide proficient weed management expertise at each administrative unit of a public land management agency. Expertise means that necessary skills are available and corporate knowledge is maintained.
- Develop or adopt weed-awareness programs or literature for local residents, fishing and hunting license-holders, outfitters, backcountry campers and other visitors.
- Develop incentive programs for personnel and visitors encouraging weed awareness, detection, reporting, and identifying new invaders.

Objective: Set an example by maintaining weed-free administrative sites.

- Treat weeds at administrative sites and visitor centers and use weed prevention practices to maintain sites in a weed-free condition.
- Post "before & after" pictures of exotic plant removal efforts to increase awareness of native vs. invaded vegetation looks like and awareness of the effort it takes to maintain natural ecosystems.

<u>*Working with Terrestrial Recreationists and Wilderness Users*</u>

Objective: Avoid moving weed seeds or propagules into the backcountry, and to prevent new weed infestations and the spread of existing weeds and to avoid or remove sources of weed seed and propagules.

- Maintain trailheads, campgrounds, visitor centers, boat launches, picnic areas, roads leading to trailheads, and other areas of concentrated public use in a weed-free condition. Consider high-use recreation areas as high priorities for weed eradication.
- Develop a list of simple prevention practices to provide to backcountry campers and fishing license-holders. This should include mention of the important role of robust, undisturbed native vegetation and biotic soil crusts in deterring weed invasions and in facilitating repair and restoration of vegetation.
- Develop a guide to assist visitors in self-inspection of vehicles and equipment at park entrance areas. Include a "most wanted" list with sketches or photos of propagules.
- Provide containers at parking lots, campgrounds, trailheads, and river access points for visitors to deposit removed seeds.
- Sign trailheads and access points that are not scheduled for treatment to assist in educating visitors on the consequences of their activities.
- In areas susceptible to weed infestation, limit vehicles to designated, maintained travel routes. Inspect and document travel corridors for weeds and treat as necessary.

Aquatic Area Management, Recreation, and Outfitting

Objectives: Prevent new weed infestations and the spread of existing weeds; avoid or remove sources of seeds and propagules; and, avoid moving weeds between bodies of water.

- Promptly post signs if aquatic invasives are found. Confine infestation; where prevention is infeasible or ineffective, close facility until infestation is contained.
- Inspect, wash and dry boats, personal watercraft, tackle, float tubes, waders, nets, downriggers, anchors, floors of boats, props, axles, trailers, bilges and all wells, bait buckets, and other boating equipment to remove or kill harmful species not visible at boat launch before transporting to new waters. Use hot (40°C / 104°F) clean water or a high-pressure sprayer, or allow boat and equipment to dry for a minimum of five days.
- Divers should clean their equipment after each use. Be especially careful to wash the buoyancy control device and other items that retain water. All gear should be rinsed with water heated to at least 40°C / 104°F and everything should be allowed to dry completely between dives.
- Construct new boat launches and ramps at deep-water sites. Restrict motorized boats in lakes near areas that are infested with weeds. Move sediment to upland or quarantine areas when cleaning around culverts, canals, or irrigation sites. Inspect and clean equipment before moving between project areas.
- Maintain l00-foot weed-free clearance around boat launches and docks.

<u>*Working with Outfitters & Contractors*</u>

Objective: Avoid moving weed seeds or propagules into the backcountry.

- Develop or adopt weed-awareness programs or literature for local residents, fishing and hunting license-holders, outfitters, backcountry campers and other visitors.
- Develop stipulations that prohibit transportation of weed contaminated forage or feeds through NPS lands.
- Noxious weeds can be introduced in livestock dung. Feed pack and saddle stock only weed-free feed for several days before traveling into the backcountry.
- Inspect, brush, and clean animals (especially hooves and legs) before entering public land. Inspect and clean tack and equipment.
- Regularly inspect trailheads and other staging areas for backcountry travel. Bedding in trailers and hay fed to pack and saddle animals may contain weed seed or propagules.
- Tie or hold stock in ways that minimize soil disturbance and avoid loss of desirable natives.
- Use weed-free feed in the backcountry

<u>*Managing Wildlife*</u>

Objective: Avoid creating soil conditions that promote weed germination and establishment.

- Periodically inspect and document areas where wildlife concentrate in the winter and spring that might result in overuse or soil scarification.
- Use weed-free materials for all wildlife management activities.

IV. Best Management Practices for Preventing Exotic Plant Invasions

A Best Management Practice (BMP) is a recommended site management and/or maintenance activity, usually based on an approach that has been shown to work effectively for the purpose intended. A BMP is based on the use of readily available equipment and/or technology. Implementation of BMPs will allow the land manager to minimize the negative consequences that can accompany almost any necessary action (for example, road maintenance, fire fighting, and camp ground modifications). Following BMPs can also reduce liability with regard to potential agency or citizen lawsuits, and can be of economic benefit to the practitioners by reducing the likelihood that cumbersome and expensive land remediation efforts will need to be undertaken.

The BMPs that follow have been adopted from those in use by other federal land management agencies, in particular the U.S.D.A. Forest Service and the D.O.I Bureau of Land Management. These practices, when implemented, can effectively reduce invasions by exotic plants on public lands in the western United States. Since each land holding is unique, site-specific solutions are not presented. Rather, land managers, with the assistance of appropriate specialists, should use this guide to identify and select the most appropriate BMPs for the land under their responsibility. BMPs may be modified as necessary in order to best achieve the goal for each type of activity covered in this guide.

Grazing Management

GOAL: Grazing management operations do NOT enhance opportunities for spread of invasive weeds on National Park Service holdings and, where possible, serve to control, limit, or reduce the spread of invasive weeds. *The practices below should be followed unless the intent of the goal can be met with a more effective practice.*

Objective: Incorporate noxious weed prevention and control practices in the management of grazing allotments.

- Consider prevention practices and cooperative management of weeds in grazing allotments. Prevention practices may include (see below for detailed recommendations):
  - Altering season of use
  - Exclusion
  - Weed control methods
  - Revegetation
  - Education
  - Activities to minimize ground disturbance
  - Preventing weed seed transportation
  - Maintaining healthy vegetation
  - Inspection
  - Reporting

Objective: Avoid or remove sources of weed seed and propagules to prevent new weed infestations and the spread of existing weeds, and to minimize transport of weed seed into and within allotments.

- If livestock may contribute to seed spread in a weed-infested area, schedule livestock use for prior to seed-set or after seed has fallen.
- If livestock were transported from a weed-infested area, annually inspect and treat entry units for new weed infestations.
- Close infested pastures to livestock grazing when grazing will either continue to exacerbate the condition or contribute to weed seed spread. Designate those pastures as unsuitable range until weed infestations are controlled.
- Whenever possible, provide supplemental feeding in a designated area so new weed infestations can be detected and treated immediately. Pelletized feed is unlikely to contain viable weed seed.
- Noxious weeds can be introduced through seeds in livestock dung. Keep new livestock (especially livestock that may have been fed poor-quality hay) in a holding field for 24 to 48 hours before releasing onto open range.

Objective: Maintain healthy, desirable vegetation that resists weed establishment.

- Manage the timing, intensity (utilization), duration, and frequency of livestock activities to maintain the competitive ability of desirable plants and retain live plant cover and litter. The objective is to manage such that grazers are prevented from selectively removing desirable plant species and leaving undesirable species.
- Manage livestock grazing on restoration areas to ensure that desired vegetation is well established. This may involve exclusion for a period of time. Consider practices to also minimize wildlife grazing on the areas, if necessary.
- Reduce ground disturbance, including damage to biological soil crusts. Consider changes in the timing, intensity, duration, or frequency of livestock use; location and changes in salt grounds; restoration or protection of watering sites; and restoration of yarding/loafing areas, corrals, and other areas of concentrated livestock use.
- Inspect areas of concentrated livestock use for weed invasion. Especially focus on watering locations and other resource-rich environments that may be particularly susceptible to invasion. Inventory and manage new infestations.
- Use education programs or annual operating instructions to increase weed awareness.

Fire Management

GOAL: Fire program operations do NOT enhance opportunities for spread of invasive weeds on National Park Service holdings and, where possible, serve to control, limit, or reduce the spread of invasive weeds. *The practices below should be followed unless the intent of the goal can be met with a more effective practice.*

Increasing Awareness during Pre-Incidence and Fire Planning Stages

Objective: Improve effectiveness of prevention practices through weed awareness and education.

- Provide training materials and training to seasonal fire staff on invasive wee identification and weed prevention BMPs.
- For prescribed burns, inventory the project area and evaluate potential weed spread with regard to the fire prescription.
- Ensure that a weed specialist is included in a Fire Incident Management Team when wildfire or control operations occur in or near a weed-infested area.
- Include weed risk factors and weed prevention considerations in all wildland fire and prescribed fire management actions.
- Provide weed documentation forms to be included with Initial Attack Incident Commander, the Prescribed Fire Monitor, and the Engine Boss, Resource Advisor, Air Operations Branch Director kits, as appropriate for type of fire incident.
- Resources can include local noxious weed pocket guides, videos such as *Noxious Weeds: A Biological Wildfire* and *Explosion in Slow Motion: Weeds on Western Lands*, and laminated identification cards such as *Leave No Weeds*.

Objective: Avoid or remove sources of weed seed and propagules to prevent spreading weeds.

- Provide dispatch with information on known weed infestation areas - update annually.
- Use operational practices to reduce weed spread (for example, avoid weed infestations when locating fire lines).

- Locate, identify, periodically inspect, and treat weeds in potential runway and helibase areas, staging areas, incident command posts & base camps, practice jump areas, etc.
- When invasive weeds have been identified on an Incident Scene, clean all vehicles that have been in infested site and insect clothing on personnel that have traveled on foot through site.

<u>*Fire Management Plans*</u>

Objective: Avoid creating post-fire conditions conducive to invasive weeds that come about due to well-intentioned, but mis-timed followup activities.

- Prescribed fire burn plans will include pre-burn invasive weed inventory and risk assessment components, as well as post-burn mitigation components.
- Integrate prescribed fire and other weed management techniques to achieve best results. This may involve post-burn herbicide treatment or other practices that require careful timing.
- Include weed prevention and follow-up monitoring in all prescribed fire activities. Include in burn plans, the possibility that post-burn weed treatment may be necessary.
- Implementation Plans for Wildland Fire for Resource Benefit will include considerations and mitigation measures for control of weed establishment and spread.

<u>*Fire Operations*</u>

Objective: Avoid or remove sources of weed seed and propagules to prevent new weed infestations and the spread of existing weeds.

- Ensure that rental and interagency equipment is free of weed seed and propagules during check-in or otherwise prior to assignment. [Also, inspect and clean all owned vehicles that have traveled off-site prior to allowing them to return home.]
- Inspect and treat weeds that establish at equipment cleaning sites after fires.
- Establish incident bases, staging areas, and landing zones in areas that are verified to be free of invasive weeds.
- If placement of operations facilities in weed-infested areas cannot be avoided, mow areas of concentrated activity if weeds are not yet setting seed. If weeds are setting seeds, designate travel routes on weed-free paths.
- Cover weed infested cargo areas and net-loading areas with tarps if weeds are on site and can't be removed or avoided.
- Flag off high-risk weed infestations in areas of concentrated activity and show weeds on facility maps.
- Establish power wash stations at or near incident bases and helibases if fire operations involve travel or work in weed infested areas. Wash all vehicles and upon arrival from and prior to departure to each incident, including fuel trucks and other service vehicles.

Objective: Avoid creating soil conditions that promote weed germination and establishment.

- Use fire suppression tactics that reduce disturbances to soil and vegetation.
- Avoid moving water buckets from aquatic-weed-infested lakes to lakes that are not infested. There is no hazard in using water infested with aquatic weeds on terrestrial sites.

- Avoid ignition and burning in areas at high risk for weed establishment or spread. Treat weeds that establish or spread.

<u>*Fire Rehabilitation*</u>

Objective: Prevent conditions favoring weed establishment and to re-establish vegetation on disturbed ground as soon as possible.

- To prevent weed spread, treat weeds in burned areas. The first preference is prevention..
- Determine soon after a fire whether revegetation is necessary to speed recovery of a competitive plant community, or whether desirable plants in the burned area will recover naturally. Consider the severity of the burn and the proportion of weeds to desirable plants on the land before it burned. In general, more severe burns and higher pre-burn weed populations increase the necessity of revegetation. Consider revegetating an area if the desired plant cover is only 20 to 30%. Apply for funding during the Incident.
- Replace soil and vegetation "green side up" when rehabilitating fire lines.
- Inspect, document, and monitor weed establishment at fire access roads, cleaning sites, all disturbed staging areas, and within burned areas. Control infestations to prevent spread within burned areas.
- Schedule recon approximately one year post-fire to identify weed infestations that may be moving into burned areas.
- Seed and straw mulch to be used for burn rehabilitation (for wattles, straw bales, dams, etc.) should be inspected and certified that they are free of weed seed and propagules.
- Regulate human, pack animal, and livestock entry into burned areas until desirable vegetation has recovered sufficiently to resist weed invasion.
- Develop a burned-area integrated weed management plan, including a monitoring component to detect and eradicate new weeds early.

<u>Maintenance, Construction, and Road Repair</u>

GOAL: Maintenance, construction, and road repair operations do NOT enhance opportunities for spread of invasive weeds on National Park Service holdings and, where possible, serve to control, limit, or reduce the spread of invasive weeds. *The practices below should be followed unless the intent of the goal can be met with a more effective practice.*

<u>*Site-Disturbing Projects and Maintenance Programs*</u>

Objectives: Incorporate weed prevention and control into project layout, design, and evaluation, as well as all project decisions and to build and maintain healthy plant communities that will effectively compete with weeds.

- Environmental analyses for projects and maintenance programs should assess weed risks, analyze high-risk sites for potential weed establishment and spread, and identify prevention practices. Determine weed prevention and management needs at the onset of project planning.
- Include site-specific vegetation monitoring objectives in project plans. Recognize desirable plants as well as weeds.

Objective: Avoid or remove sources of weed seed and propagules to prevent new weed infestations and the spread of existing weeds.

- Before ground-disturbing activities begin, inventory and prioritize weed infestations for treatment in project operating areas and along access routes. Identify what weeds are on site or within the vicinity and do a risk assessment accordingly. Control weeds as necessary.
- Begin project operations in non-infested areas. Restrict movement of equipment and machinery *from* weed-contaminated areas *to* non-contaminated areas. This includes machinery used for or by construction, recreation, agriculture, forestry, oil and gas exploration and production, utility companies, mining, and tourism.
- Locate and use weed-free project staging areas. Avoid or minimize travel through weed-infested areas, or restrict travel to periods when spread of seed or propagules is least likely.
- Identify sites where equipment can be cleaned. Remove mud, dirt, and plant parts from project equipment before moving it into a project area. Seeds and plant parts should be collected and incinerated when practical.
- Clean all equipment before leaving the project site if operating in weed infested areas.
- Inspect, remove, and properly dispose of weed seed and plant parts found on clothing and equipment. Proper disposal means bagging and incinerating seeds and plant parts.
- Coordinate project activities with nearby herbicide applications to maximize cost effectiveness of weed treatments.
- Evaluate options to regulate the flow of traffic on sites where desired vegetation needs to be established or maintained.

Objectives: Prevent the introduction and spread of weeds caused by moving infested sand, gravel, and fill material and to work with and encourage the responsible transportation agencies to voluntarily adopt these practices.

- Inspect materials on origination site to ensure that they are weed-free before transport and use. If sources of sand, gravel, and fill are infested, eradicate weeds, then strip and stockpile the contaminated material for several years, if possible, checking regularly for weed re-emergence.
- When material from a weed-infested but treated source is used in a project, inspect and document the project area annually for at least three years to ensure that any weeds transported to the site are promptly detected and controlled.
- Maintain stockpiled, non-infested material in a weed-free condition.

Objective: Avoid creating environmental conditions that promote weed germination and establishment.

- Minimize soil disturbance.
- If a disturbed area must be left bare for a considerable length of time, cover the area with plastic until revegetation is possible.
- When working in vegetation types with relatively closed canopies, retain shade to the extent possible to suppress weeds and prevent establishment and growth.
- Retain native vegetation in and around project activity as much as possible.

Objective: Re-establish vegetation to prevent conditions conducive to establishment of weeds when project disturbances create bare ground.

- Revegetate disturbed soil to optimize plant establishment for that specific site. Define for each project what constitutes disturbed soil and objectives for revegetation.
- Revegetation may include topsoil replacement, planting, seeding, fertilization, liming, and weed-free mulching as necessary. Use native material where appropriate and feasible. Consider hiring a contractor to chip local brush or cut and bale local weed-free grass for mulch - an added benefit is that seeds in the grass or brush can help restore localized vegetation on the site. Use certified weed-free or weed-seed-free hay or straw where certified materials are required or available.
- Monitor sites where seed, hay, straw, or mulch has been applied. Eradicate weeds before they seed. In contracted projects, contract specifications can require that the contractor maintain the site weed-free for a specified time.
- Where practical, stockpile weed-seed-free topsoil and replace it on disturbed areas (for example, road embankments or landings).
- Use local seeding guidelines to determine procedures and appropriate seed mixes. A certified seed laboratory needs to test each lot according to Association of Seed Technologists and Analysts (AOSTA) standards (which include an all-state noxious weed list) and provide documentation of the seed inspection test. Check state and federal lists to see if any local weeds need to be added prior to testing. Non-certified seed should be tested before use.
- Inspect and document all ground-disturbing operations in noxious weed infested areas for at least three growing seasons following completion of the project. For ongoing projects, continue to monitor until reasonably certain that no weeds have appeared. Plan for follow-up treatments based on inspection results.

Objective: Incorporate weed prevention into road and utility project layout, design, evaluation, and decisions.

- Remove mud, dirt, and plant parts from project equipment before moving it into a project area. Seeds and plant parts should be collected and incinerated when practical.
- Clean all equipment before leaving the project site if operating in areas infested with weeds. Seeds and plant parts should be collected and incinerated when practical.
- Communicate with the local weed district or weed management area about projects and best practices for prevention.
- To avoid weed infestation, build and maintain healthy plant communities whenever possible, including utility rights of way, roadsides, highway landscaping projects, rest area construction, scenic overlooks, and entrances.

Objective: Minimize roadside sources of weed seed that could be transported to other areas.

- Periodically inspect roads and rights-of-way for noxious weeds. Train road maintenance staff and utility truck operators to recognize weeds and report locations to the local weed specialist. Inventory weed infestations and schedule them for treatment.
- Restrict transportation of non-certified weed-free forage and hay on through roads.
- Schedule and coordinate blading or pulling of noxious weed-infested roadsides or ditches in consultation with the local weed specialist. Do not blade or pull roadsides and ditches infested with noxious weeds unless doing so is required for public safety or protection of

the roadway. If the ditch must be pulled, ensure weeds remain on-site. Blade from least infested to most infested areas. When it is necessary to blade noxious weed-infested roadsides or ditches, schedule activity when seeds or propagules are least likely to be viable and spread.

- Avoid acquiring water for road dust abatement where access to water is through weed-infested sites.
- Treat weeds in road decommissioning and reclamation projects before roads are made impassable. Re-inspect and follow up based on initial inspection and documentation.

V. Additional Materials and Further Information

Selected Relevant Literature:

Hobbs, R.J. and S.E. Humphries. 1995. An integrated approach to the ecology and management of plant invasions. *Conservation Biology* 9:761-770.

Luken, J.O. and J.W. Thieret, editors. 1997. *Assessment and Management of Plant Invasions*. Springer-Verlag, New York, NY. 324pp.

Pickett, S.T.A., S.L. Collins and J.J. Armesto. 1987. Models, Mechanisms and Pathways of Succession. *The Botanical Review* 53:335-371.

Whisenant, S.G. 1999. *Repairing Damaged Wildlands: A Process-Oriented, Landscape-Scale Approach*. Cambridge University Press, Cambridge, UK. 312pp.

White, P.S. and S.T.A. Pickett. 1985. Natural disturbance and patch dynamics: an introduction. Pages 3-13 in S.T.A. Pickett and P.S. White (eds). *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press, San Diego.

Whitford, W.G. 2002. *Ecology of Desert Systems*. Academic Press, San Diego. 343 pp.

Links to weed sites: (and general plant and management sites with good weed information)

Title	Link
Databases	
Global Invasive Species Database	http://www.issg.org/database/welcome/
The PLANTS Database	http://plants.usda.gov/index.html
Invaders Database System	http://invader.dbs.umt.edu/
Integrated Taxonomic Information System	http://www.itis.usda.gov/
Information: Gov. Sites	
BLM's Weed Website	http://www.blm.gov/weeds/
Information: Non-Gov. Sites	
TNC Wildland Invasive Species Program page	http://tncweeds.ucdavis.edu/
Exotic Plants Bibliography	http://www.npwrc.usgs.gov/nextbuild/resource/literatr/exotic/exotic.htm
Invasive Species Node Home Page (NBII)	http://www.nrel.colostate.edu/projects/nbii/nbii.html

Title	Link
Invasive Species: The Nation's Invasive Species Information System	http://www.invasivespecies.gov/index.shtml
Invasive Species: National Invasive Species Management Plan	http://www.invasivespecies.gov/council/nmp.shtml#html
Plant Conservation Alliance - Alien Plant Working Group	http://www.nps.gov/plants/alien/
Southwest Exotic Plant Information Clearinghouse	http://www.usgs.nau.edu/SWEPIC/index.html
Preserving Our Natural Heritage - A Strategic Plan for Managing Invasive Nonnative Plants on National Park System Lands	http://www1.nature.nps.gov/wv/strat_pl.htm
NBII - ISIN	http://invasivespecies.nbii.gov/index.html
Invasive Weeds	http://www.invasiveweeds.org/
NAWMA	http://www.nawma.org/
NPS Alien Plant Working Group - Info Links	http://www.nps.gov/plants/alien/moreinfo.htm
Nonindigenous Aquatic Species	http://nas.er.usgs.gov/fishes/fishes.htm
Noxious Times Noxious Invasive Weed Newsletter	http://pi.cdfa.ca.gov/noxioustimes/
Noxious Weeds: A Biological Wildfire	http://extension.usu.edu/publica/agpubs/wildfire.pdf
Exotic and Invasive Species on the Colorado Plateau	http://www.cpluhna.nau.edu/Biota/invasive_exotics.htm
Invasive Species: Manager's Tool Kit	http://www.invasivespecies.gov/toolkit/main.shtml
Weeds Website	http://www-a.blm.gov/weeds/
States: UTAH	
BLM Utah Weed Program	http://www.blm.gov/utah/resources/weeds/
THE WEED WEB	http://extension.usu.edu/weedweb/index.htm
BLM-Bureau of Land Management-Utah-Healthy Productive Lands-Noxious Weeds	http://www.ut.blm.gov/wh3noxweeds.html
Moab Field Office	http://www.ut.blm.gov/moab/index.html
BLM Utah, Moab Field Office Home Page	http://www.blm.gov/utah/moab/index.html
States: Colorado	
Colorado Weed Management Association	http://www.cwma.org/
Weed Watch (CWMA Newsletter)	http://www.cwma.org/5_news.html
Colorado Department of Agriculture	http://www.ag.state.co.us/
Noxious Weed Program	http://www.ag.state.co.us/dpi/weeds/weed.html
BLM Colorado - Weed Management Home Page	http://www.co.blm.gov/botany/weedhome.htm
States: OTHER	
California Exotic Pest Plant Council	http://www.caleppc.org/
Miscellaneous Sites	
THE ECOLOGY OF INVASIVE SPECIES	http://culter.colorado.edu:1030/~tims/class00.html
Invasive Plants & Animals in Iowa: A Symposium	http://www.ag.iastate.edu/departments/aecl/invasives/
Center for Invasive Plant Management	http://www.weedcenter.org/
Cooperative Extension Catalog of Publications--Weeds	http://www.ianr.unl.edu/pubs/Weeds/index.htm

Title	Link
Colorado State Cooperative Extension Natural Resources Publications	http://www.ext.colostate.edu/PUBS/NATRES/pubnatr.html

Other Best Management Principles Guidelines:

Title	Link	Comments
Guides		
Ecological Invasive Plant Management Textbook	http://www.weedcenter.org/textbook/index.html	Center for Invasive Plant Management
Integrated Weed Management Guidelines	http://www.blm.gov/education/weed/paws/IWM21.html	Colorado Integrated Weed Management Plant, Partners Against Weeds (PAWs)
Noxious Weed Management Amendment	http://www.co.blm.gov/botany/lolostip.htm	USFS Lolo National Forest Plan
Guidelines for Coordinated Management of Noxious Weeds	http://www.weedcenter.org/management/management.html	Center for Invasive Plant Management

Sample brochures (templates, activities), etc.:

Title	Link	Comments
Brochures		
Tours		
California Weed Awareness Week	http://groups.ucanr.org/ceppc/Organizing_a_weed_tour/	CalEPPC

Guidelines and Standards for Weed Management Areas:

Title	Link	Comments
Guidelines for Coordinated Management of Noxious Weeds: Development of Weed Management Areas	http://www.weedcenter.org/management/guidelines/tableofcontents.html	Center for Invasive Plant Management [Includes sample contracts, agreements and memoranda of understanding]
Guidelines for Prioritizing Weed Management	http://tncweeds.ucdavis.edu/products/ww-wb/wwwbapp4.rtf	An appendix from a TNC guide
Guidelines for Noxious Weed Management Plans	http://www.co.weld.co.us/departments/weed_pest/pdf/Guide4WeedManPlan.pdf	For Weld Cty, Colorado

Appendix G. Program Update – NCPN Data Mining

Prepared by:

Margaret Beer, NCPN
Elizabeth Nance, NCPN

14 August 2003

Data mining and data development work continued in 2003; however, the volume of new records acquired and entered into several network databases decreased from previous years. This decrease is to be expected as backlogs diminish, and as we focus on improving existing records and locating data that might be older, more obscure, or difficult to interpret or obtain.

Work in NatureBib (a bibliographic database of documents, reports and publications relating to park natural resources) focused primarily on evaluating, correcting or deleting records; and on entering records related to recent projects, specific subjects (e.g., T&E birds) or specific sources (e.g., Investigator's Annual Reports) (Table G-1).

Approximately 30 new data sets were documented in the Dataset Catalog, and all records for seven parks were reviewed and updated.

Work has also begun on developing the NPSpecies database – a system which tracks the status, residency, abundance, and nativity of vertebrate and vascular plant species in network parks. Results from 2001 and 2002 vertebrate inventories have been entered; new downloads of vertebrate specimen data from park museum databases were requested and are being incorporated; and procedures and field standards have been defined and documented (Table G-2).

The network continued to acquire and develop park-specific and regional GIS data sets. These included digital orthophoto quarter-quads (DOQQs) resulting from the network vegetation mapping project, 90-m digital-elevation-model (DEM) data for the NCPN region, 1:100K and 1:24K hydrographic data from the National Hydrological Database for all watersheds intersecting network parks, spatial data for locations of SEUG monitoring projects, and finalized coverages of location data from 2001 and 2002 inventories. We currently have approximately 1200 GIS coverages in the network inventory.

Other data-related projects conducted during the past year include the development of procedures to manage slides, photos, and digital images. Approximately 800 images relating to I&M project work have been catalogued. In addition, NCPN staff designed a MS Access database for tracking data requests made to program staff.

Table G-1. Summary of NCPN data mining and data development work associated with NatureBib database, October 1, 2002 - September 30, 2003.

Actions	Count of Current Records	
• Quality-controlled all records and removed approximately 3,000 entries that were duplicates, incomplete, or not relevant to the database scope. • Entered over 100 new records to the database, with attention to T&E birds, Investigator's Annual Reports, and new or recent documents. • Reviewed Utah BLM natural resource bibliography; entered references pertinent to network parks. • Updated database documentation and training manual. • Established standards for individual park and Park Service citations	ARCH	899
	BLCA	308
	BRCA	763
	CANY	1316
	CARE	1143
	CEBR	190
	COLM	476
	CURE	444
	DINO	1355
	FOBU	219
	GOSP	98
	HOVE	242
	NABR	332
	PISP	99
	TICA	251
	ZION	825
	Total	8960

Table G-2. Summary of NCPN data mining and data development work associated with the NPSpecies database, October 1, 2002 - September 30, 2003.

Actions	Count of Current Records		
• Standardized database fields, values and definitions • QA/QC of all T&E bird entries • Entered all reptile and amphibian voucher data from the 2001-2002 NCPN I&M inventories • Entered all reptile and amphibian voucher data from park museum collections (ANCS+) • Entered all vegetation voucher data from ANCS+ for ZION • Standardized network import procedures for ANCS+ voucher data • Entered all mammal voucher data from ANCS+ for the following parks: ZION, ARCH, CANY, NABR, CEBR, COLM, DINO, TICA and GOSP • Entered all mammal voucher data resulting from 2001-2002 inventories Note: number of records reflects an inflated species count due to synonyms.		Vertebrates	Plants
	ARCH	589	963
	BLCA	276	553
	BRCA	462	785
	CANY	747	1149
	CARE	1107	1472
	CEBR	281	579
	COLM	425	668
	CURE	499	790
	DINO	692	1123
	FOBU	544	817
	GOSP	121	338
	HOVE	412	666
	NABR	501	843
	PISP	166	310
	TICA	518	795
	ZION	931	1616

Appendix H. Program Update – NCPN Development of Ecological Conceptual Models

Prepared by:

Mark Miller, USGS-BRD

17 August 2003

The workload associated with managing the vital-sign selection process from fall 2002 through summer 2003 prevented NCPN staff from advancing the monitoring-plan chapter on ecological conceptual models beyond what was presented in the Phase I report. However, NCPN has engaged in several activities associated with continued development and refinement of conceptual models.

Coordination with Southern Colorado Plateau Network

In February 2003, the NCPN ecologist (Miller) met with the Southern Colorado Plateau Network (SCPN) program manager and technical committee to discuss the NCPN approach to conceptual modeling. The outcome of the meeting was that the SCPN agreed to adopt the general conceptual framework of the NCPN (the Jenny-Chapin model of ecosystem sustainability) and to work together with the NCPN in the further development and refinement of more-detailed conceptual models.

An additional meeting was held in June 2003, during which further steps were made to align the conceptual approaches of the two networks (see body of Phase II report). As part of this effort, the two networks together prepared guidelines for cooperators developing ecological conceptual models in support of the SCPN and NCPN. A working draft of these guidelines is presented in Appendix I to the Phase II report (subsequent to this appendix). To date, these guidelines have been used to focus model development for montane ecosystems by John Vankat and for springs, seeps, and hanging-garden ecosystems by Larry Stevens, Al Springer and John Spence. The latter effort represents the first significant joint project between the SCPN and NCPN.

In conjunction with the development of protocols for monitoring riparian ecosystems (funded with FY03 USGS protocol-development money), Mike Scott of USGS-BRD in Fort Collins will develop riparian conceptual models in partnership with USGS-BRD in Moab (Miller). An initial planning meeting was held in Moab during July 2003 (see Appendix E).

The current vision is that the two networks ultimately will have identical (or nearly identical) monitoring-plan chapters pertaining to ecological conceptual models. It is anticipated that the former NCPN ecologist (now with USGS-BRD in Moab) will continue to work with both networks in continued development and integration of conceptual models.

Partnership Approach to Development of State-and-Transition Models

In June 2003, a workshop was held in Moab to discuss NCPN needs for soil-resource inventories and associated ecological state-and-transition models. (State-and-transition models are developed for particular *ecological sites* – a concept which is intimately linked to soils.) The workshop included participants from NPS, USDA Natural Resource Conservation Service (NRCS) and Agricultural Research Service (ARS), USGS, Bureau of Land Management (BLM), and The Nature Conservancy (TNC) (Table H-1).

Two important outcomes of this meeting were (1) development of an NPS-NRCS agreement to assess current soil-resource inventories and, as required, conduct new soil-resource inventories for NCPN parks in Utah, and (2) agreement to form a partnership for the development of site-specific state-and-transition models applicable to lands managed by NPS, TNC, and BLM in Utah. Up-to-date soil-resource inventories and ecological site descriptions (including site-specific state-and-transition models) are required for assessments of upland ecosystem conditions, explicit identification and cross-site correlation of benchmark ecosystems (reference sites), stratification of monitoring efforts, and facilitation of coordinated ecological monitoring across ownership boundaries. TNC and USGS-BRD will jointly coordinate and host a state-and-transition modeling workshop in Moab in November 2003.

Table H-1. Participants in workshop on NCPN needs for soil-resource inventories and ecological state-and-transition models, Moab, June 2003.

Name	Position / Affiliation
Pete Biggam	Soil Scientist, NPS, Natural Resource Information Division, Denver, CO
Angie Evenden	Program Manager, NPS, Northern Colorado Plateau Network, Moab, UT
Mark Miller	Ecologist, NPS, Northern Colorado Plateau Network, Moab, UT
Gery Wakefield	GIS manager, NPS, Southeast Utah Group, Moab, UT
Jayne Belnap	Research Ecologist, USGS-BRD, Moab, UT
Dave Miller	Research Geologist, USGS-GD, Menlo Park, CA
Alan Flint	Research Hydrologist, USGS-WRD, Sacramento, CA
Lorrie Flint	Research Hydrologist, USGS-WRD, Sacramento, CA
Brandon Bestelmeyer	Ecologist, USDA-ARS, Jornada Experimental Range, Las Cruces, NM
Bill Broderson	State Soil Scientist, NRCS, Salt Lake City, Utah
Cameron Loerch	State Soil Scientist, NRCS, Denver, Colorado
Phil Camp	State Soil Scientist, NRCS, Phoenix, Arizona
George Peacock	Rangeland Ecologist, NRCS Grazing Lands Technology Institute, Ft. Worth
Larry Ellicott	Rangeland Management Specialist, NRCS, Salt Lake City, Utah
Kent Sutcliffe	Soil Scientist, NRCS, Cedar City, UT
Suzanne Mayne	Rangeland Management Specialist, NRCS, Cedar City, UT
Bill Ypsilantis	Soil Scientist, BLM, National Science & Technology Center, Denver, CO
Steve Deeter	Rangeland Management Specialist, NRCS, Monticello, UT
Lynn Jackson	Colorado Plateau Science Coordinator, BLM, Moab, UT
Sue Bellagamba	Canyonlands Program Director, The Nature Conservancy, Moab, UT
Joel Tuhy	Director of Conservation Science, The Nature Conservancy, Moab, UT

Appendix I. NCPN and SCPN Guidance for Cooperators Developing Ecological Conceptual Models

[This appendix presents a DRAFT set of conceptual modeling guidelines developed jointly by the NCPN and the SCPN. This and future versions of the guidelines will be used by the two networks to guide cooperators in the development of conceptual models to be used by both networks.]

Prepared by:

Mark Miller, USGS-BRD
Lisa Thomas, NPS Southern Colorado Plateau Network
(equal coauthors)

16 July 2003 WORKING DRAFT

The purpose of this document is to provide guidance to cooperators working on conceptual ecosystem models for the Northern Colorado Plateau Network (NCPN) and the Southern Colorado Plateau Network (SCPN) of the National Park Service's Inventory and Monitoring Program (NPS I&M Program). Ultimately, this guidance is intended to facilitate consistency in modeling approaches across systems, cooperators, and the two Colorado Plateau I&M networks.

In this document, we provide the following: (1) working definitions of the concepts of ecosystems and ecosystem integrity, (2) a brief overview of important concepts concerning ecosystem structure, functioning, and dynamics, and (3) describe three general types of models (with examples) that we envision

Ecosystems and ecosystem integrity

We define an *ecosystem* as "a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries" (Likens 1992, cited by Christensen et al. 1996:670). This geographical approach to ecosystems ("geo-ecosystems" of Rowe and Barnes 1994) is consistent with classification schemes developed for riverine systems (Rosgen 1994) and terrestrial land units (Bourgeron et al. 2001) that have proven useful for purposes of ecological resource assessments, monitoring design (i.e, stratification), and landscape-level ecological modeling.

We adopt the concept of *ecological integrity* as an appropriate foundation for assessing the state of ecological systems (Karr 1991, 1996; De Leo and Levin 1997; Noon 2003). A system with integrity may be defined as having the capacity to support and maintain a balanced, integrated, and adaptive community of organisms having the full range of biotic components (genes, species, assemblages) and processes (mutation, demography, biotic interactions, energetics, nutrient cycling) expected from natural ecosystems of the region (Karr and Dudley 1981; Karr 1991, 1996). An ecosystem approach requires full consideration of the geophysical template that supports the biota, thus abiotic components (e.g., soil resources) and processes (e.g., hydrology) of ecosystems also are encompassed within our definition of ecosystem integrity.

We have adapted a suite of ecosystem characteristics developed by Harwell and others (Harwell et al. 1999) to link our monitoring objectives to structural and functional ecosystem attributes. These characteristics are consistent with the overarching NPS management goal of restoring and maintaining the ecosystem integrity of park lands and relate directly to more specific park management objectives (Table I-1).

Table I-1. Management objectives and related landscape or ecosystem characteristics relating to the goal of restoring and maintaining ecosystem integrity.

Management Objective	**Related Ecosystem Characteristic**
Provide the spatial extent, mosaic landscape pattern and connectivity required to support the natural diversity of ecosystems and species.	**System Dimensions** - Landscape patterns
Protect soil resources and restore soil quality of disturbed lands.	**Soil, Water and Nutrient Dynamics** - Upland soil stability and hydrologic function - Stream flow regime and hydrologic function - Groundwater dynamics
Restore or maintain hydrologic function and protect ground and surface water quality and quantity.	
Reduce pollution in park water bodies and protect water quality of pristine waters.	- Water quality
Provide for sustainable populations and communities of native species.	**Biotic Integrity** - Status of predominant plant communities - Status of at-risk species or communities - Status of endemic species or unique Colorado Plateau Communities - Status of focal species or communities
Restore the structure, native species composition and natural processes of disturbed lands.	
Reduce the spatial extent and abundance of established invasive non-native species and prevent new establishment.	
Restore fire-adapted systems.	**Disturbance Regimes** - *Fire regimes and their disruption* - Extreme climatic events - Insect / disease outbreaks in forests and woodlands
Understand the role of extreme climatic events and climate cycles in driving ecosystem processes	**Atmospheric and Climate Conditions** - Climate - Air quality
Improve and protect regional air quality.	

Intrinsic vs. anthropogenic variability

Detecting meaningful change is complex because ecosystems are inherently dynamic and spatially heterogeneous. Yet an important goal of monitoring is to differentiate the effects of intrinsic variability from those resulting from human–induced patterns of change (Osenberg et al. 1994, Mulder et al. 1999). The aims of characterizing natural variability are to understand how driving processes yield different effects from site to site, reconstruct how these processes influenced systems in the past, and predict future outcomes (Landres et al. 1999). Historical ecology informs us about the pathways that brought ecosystems to their current state and may help identify anomalous conditions (Swetnam et al. 1999). Thus, the historic range of natural variability provides an important context for evaluating current anthropogenic effects despite the likelihood that current and future changes in atmospheric chemistry, climatic conditions, and land-use / land-cover patterns will render historic patterns of variability less and less attainable over time.

A primary goal of conceptual models is to describe our understanding of how natural drivers influence key structural ecosystem components, their functional relationships and interactions, and system dynamics. Depending upon stochastic and cyclic variability in climate attributes, key disturbance patterns and other driving forces, we expect to observe a range of dynamic states in structural ecosystem attributes. Our ability to detect the effects of current anthropogenic stressors is dependent upon interpreting trends in resource condition against the backdrop of intrinsic variation. Hypotheses concerning the effects of anthropogenic stressors on ecosystem structure and function must be grounded in an understanding of the relationship between natural drivers and the structure and dynamics of ecosystems.

A nested family of conceptual models

No single conceptual model can satisfy all needs. Spatially explicit applications such as ecological resource assessments, monitoring design (i.e, stratification), and landscape-level ecological modeling ultimately will require site-specific models, but the the I&M program also requires generalized ecological models to facilitate communication among scientists, managers, and the public regarding ecosystems and how they are affected by human activities and natural processes. We will employ an iterative process of first developing general conceptual models for broadly defined ecosystem types, and then adapting and refining those models as we build an information base of site-specific data concerning abiotic constraints, local land-use history, current condition, and spatiotemporal ecosystem dynamics. An important application of these generalized models will be to guide the selection and prioritization of vital signs (indicators) for monitoring. Guidance in this document is aimed toward the development of these generalized models – but while developing the general models, cooperators should keep the site-specific models in mind. Ideally, site-specific models will represent variations in the details associated with the general model. Thus site-specific models should be recognizably related to the general models.

For each modeled ecosystem, we envision three basic types of nested conceptual models (Fig. I-1). These are (1) general ecosystem characterization models, (2) ecosystem dynamics models, and (3) mechanistic models. Relatively detailed models are nested within relatively simple models. Ecosystem dynamics models present hypotheses concerning dynamics of selected components of the ecosystem (in this case of Fig. I-1, the soil-vegetation subsystem). Mechanistic models provide details concerning the actual ecological processes responsible for patterns depicted in the dynamic models. For a given type of ecosystem, several dynamic submodels and mechanistic models may be required. Figure I-2 illustrates the nested array of models that may be required. Ideally, a unique ecosystem characterization model is paired with each of the dynamic models (contrary to the depiction in Fig. I-2).

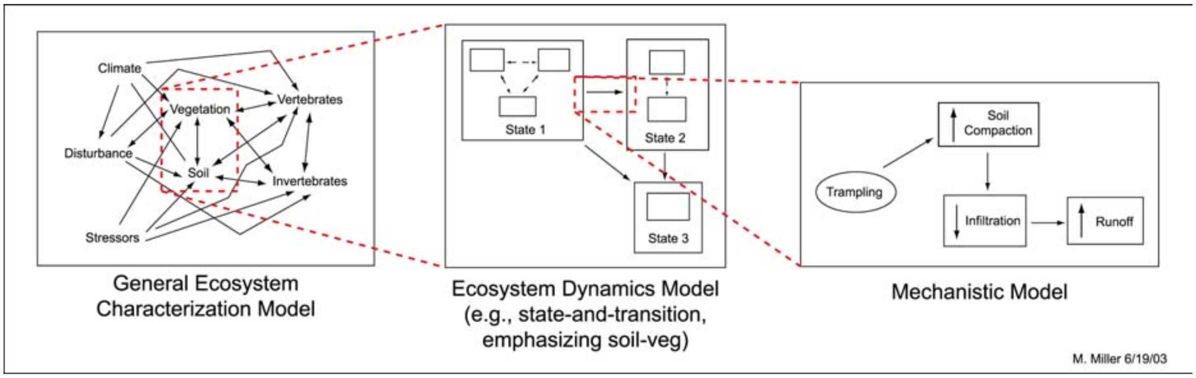


Figure I-1. Diagram illustrating relationships among three general types of models discussed in this document. Relatively detailed models are nested within relatively simple models.

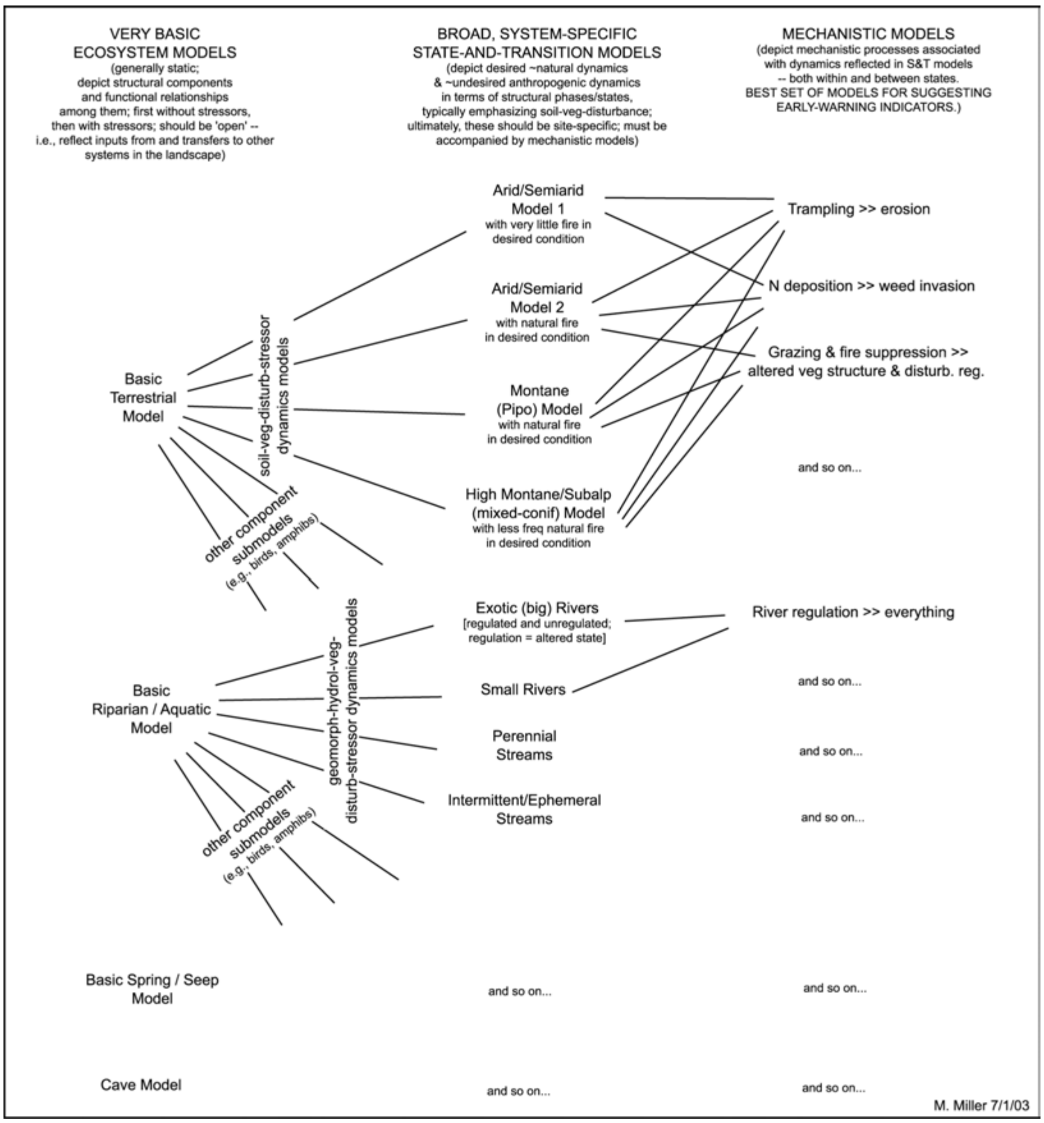


Figure I-2. Schematic depicting general types and relationships of conceptual ecological models proposed for the SCPN and NCPN monitoring plans. In addition to those depicted, several other types of models will be required – e.g., population models for TES taxa, landscape-level models for broad-ranging species and among-system relationships, and heuristic models for communicating theoretical concepts pertaining to ecosystem dynamics.

Diagrammatic models alone are insufficient for our purposes. It is essential that diagrammatic models be accompanied by narrative literature reviews/syntheses (thoroughly cited) that provide the scientific basis for the diagrams. Tables or matrices may be used to organize and summarize additional information pertaining to the diagrammatic models.

Further details and examples are provided below.

Basic Ecosystem Characterization Models

An ecosystem conceptual model can be considered as a list of state variables and forcing functions of importance to the ecosystem and the problem in focus, but will also show how these components are connected by means of processes (Jorgensen 1986). Allen and Hoekstra (1992) emphasize that "we do not wish to show that everything is connected, but rather to show which minimal number of connections that we can measure may be used as a surrogate for the whole system in a predictive model." An important step in model construction is to identify an appropriate level of resolution, given the model objectives (Starfield and Bleloch 1986). Processes that occur much more slowly than the system of interest may be aggregated and considered as constraints of the system; processes that occur more rapidly than the system of interest may be aggregated and considered as 'noise' (Turner and O'Neill 1995).

Purposes of the general ecosystem characterization model –

- To indicate the driving abiotic factors that constrain the system, depict their relationships to key structural components and processes, and describe resultant ecosystem characteristics.

- To describe the predominant natural disturbances that historically influenced the system, indicate their relative importance in structuring the system, and summarize ecosystem-specific disturbance patterns (return intervals, extent, magnitude, seasonality).

- To characterize the prevalent anthropogenic stressors that are currently affecting the system, describe their relationships to key structural components and processes, and describe resultant ecosystem effects.

- To provide a foundation for evaluating the range of current conditions of key structural components within the context of historic natural variability.

The reader should be able to compare and contrast diagrammatic models for different systems and recognize important structural and functional similarities and differences between systems that have implications for monitoring. For example, cyclic or episodic drought may be a common overriding determinant of ecosystem dynamics on the Colorado Plateau and would be portrayed similarly across the models. In contrast, the relative importance of fire as a natural driver and the extent to which a legacy of fire suppression has altered vegetation structure varies widely across these ecosystems and should be characterized accordingly.

Work by Chapin et al. (1996) on ecosystem sustainability and Harwell et al. (1999) on ecosystem integrity together outline a framework for the categories of ecosystem components / attributes to be considered in the general ecosystem characterization model. With respect to biotic ecosystem components responsible for contributing to ecosystem sustainability, Chapin and colleagues emphasize a functional-group perspective (Fig. I-3). The concept of ecosystem integrity emphasizes the full range of biotic components, irrespective of functionality.

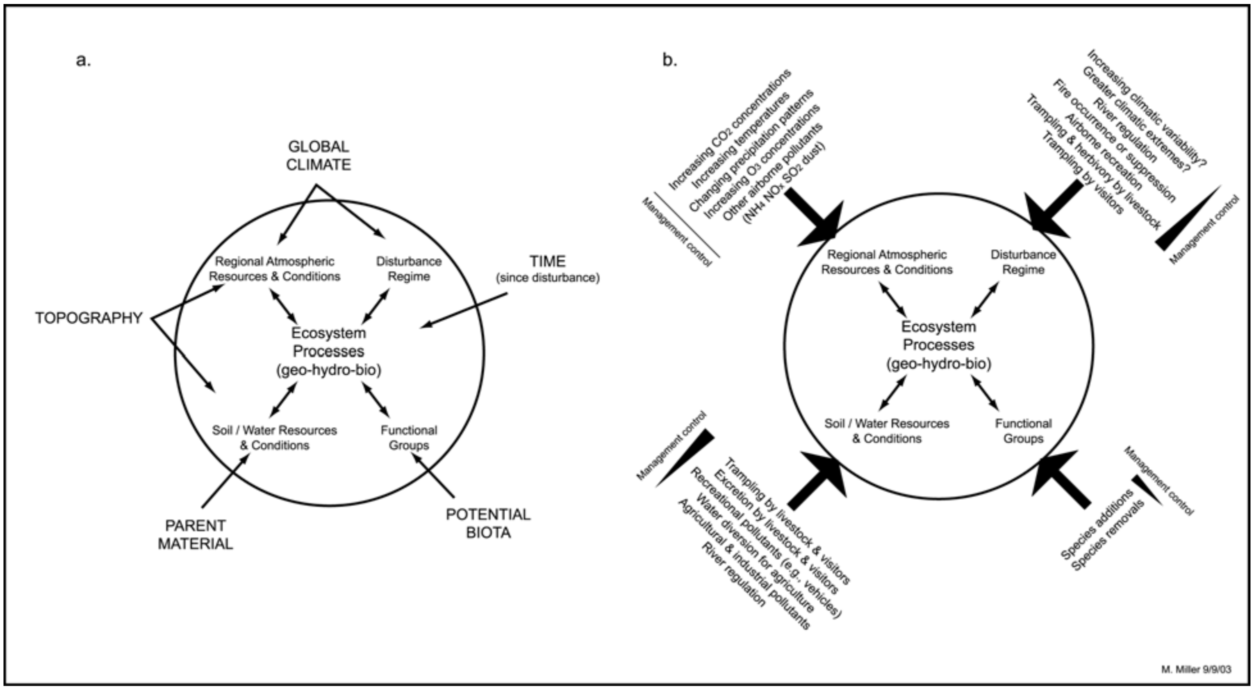


Figure I-3. Modified version (a) of Chapin and colleagues' (1996) model of ecosystem sustainability, and (b) the array of stressors affecting NCPN and SCPN ecosystems arranged in the model in relation to their first-order effects and degree of management control. In (a), the five factors outside the circle represent ultimate constraints on structural and functional characteristics of the ecosystem. Factors arranged around the inside perimeter of the circle (representing the ecosystem) are termed interactive controls of ecosystem sustainability.

Figure I-4 is a diagrammatic example of a basic ecosystem characterization model. The diagrammatic model is presented first without anthropogenic stressors, and then again with anthropogenic stressors (this latter diagram, with stressors, is not represented in the example). The model is incomplete without a narrative literature review. As indicated above, tabular information may be used to supplement the diagrammatic model. [See Table I-3 for an excessively detailed version of a tabular ecosystem characterization model.]

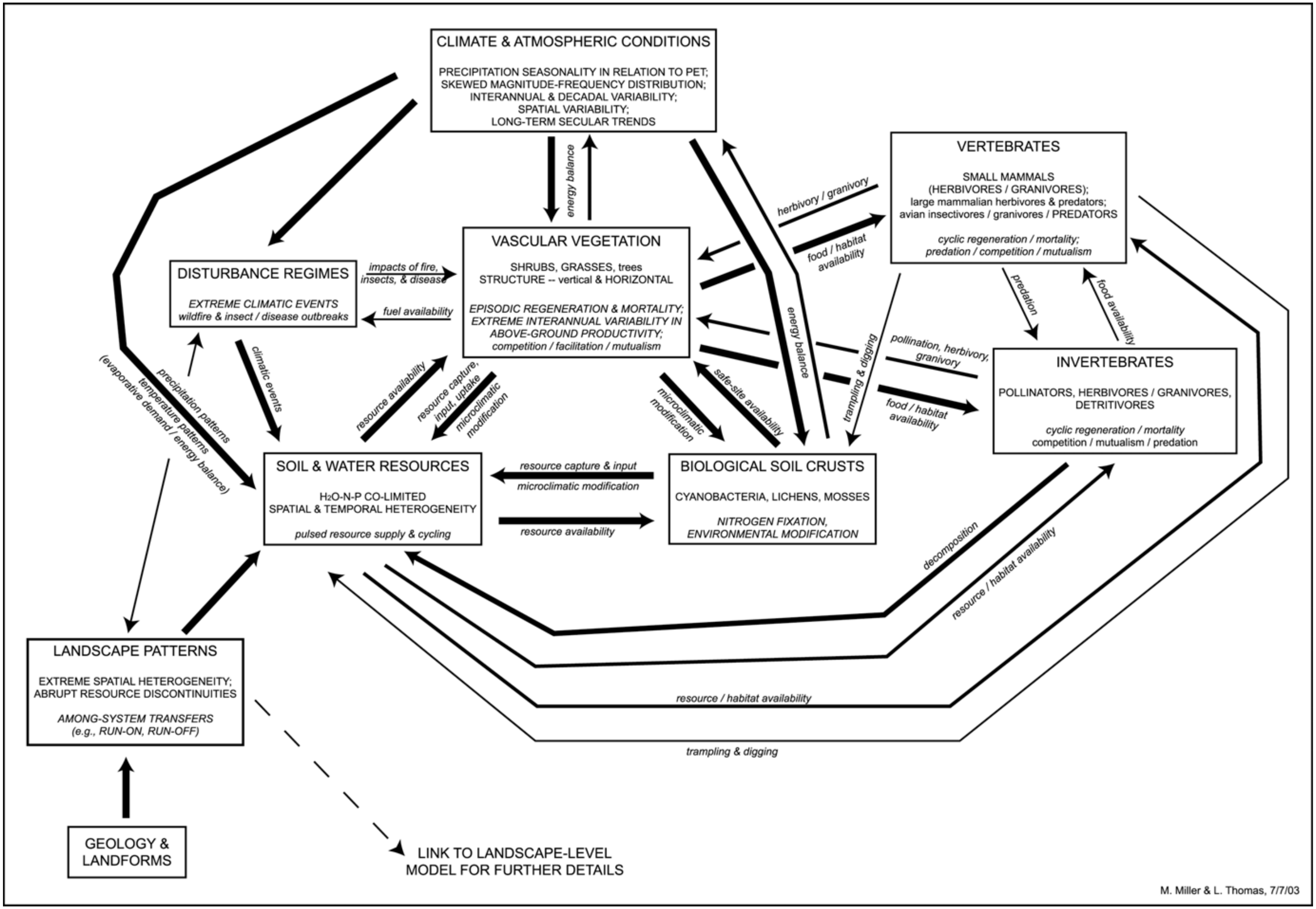


Figure I-4. DRAFT ecosystem characterization model for arid-semiarid Colorado Plateau ecosystems in which fire is a relatively minor component of the historic natural disturbance regime. The relative significance of different components, characteristics and processes is indicated by upper-vs-lower case lettering and weight of arrows. Processes are indicated by italics. The model is incomplete without a narrative literature review.

Ecosystem-Dynamics Models

Three of the five servicewide goals for vital-signs monitoring are oriented towards the *dynamics* of ecosystems or selected ecosystem components:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.

It is clear from these goals that a fundamental purpose of vital-signs monitoring is to detect meaningful changes in the condition (structure and functioning) of park ecosystems. It is therefore essential that conceptual models developed to support vital-signs monitoring reflect the current state of knowledge regarding ecosystem dynamics – how and why ecosystems change as a consequence of interacting natural and human factors.

Ecosystem-dynamics models thus represent the next level of detail in conceptual modeling required by the NCPN and SCPN. Initially, dynamic models will be developed for broad functional groupings of ecosystems – but we anticipate that site-specific models eventually will be required for some systems. Several organizations (e.g., USGS, USDA-ARS, NRCS, BLM, TNC) currently are working on site-specific *state-and-transition models* for particular *ecological sites*[1]. State-and-transition models generally have been used to describe the temporal dynamics of rangeland ecosystems, but they also have been applied to riparian ecosystems (e.g., Richter and Richter 2000, Stringham et al. 2001b). State-and-transition models for upland ecological sites typically focus on soil quality (primarily dynamic soil properties) and vegetation composition/structure because of strong soil-vegetation feedbacks and the significance of soil and vegetation for structuring other biotic components of the ecosystem. Riparian and spring/seep state-and-transition models probably would focus on vegetation, geomorphology, and hydrology / geohydrology. Figure I-5 illustrates the general structure and format of a state-and-transition model. A full review of state-and-transition models is beyond the scope of this guidance document, so cooperators should see Bestelmeyer et al. (2003) for a recent review on the development and application of these models. Stringham et al. (2001a) is another good resource.

In addition to the previously cited works on state-and-transition models, we recommend that cooperators also review the following key papers for important concepts regarding ecosystem dynamics – Scheffer et al. (2001), Paine et al. (1998), and Grimm and Wissel (1997).

[1] An *ecological site* is defined as "a kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management" (Society for Range Management, Task Group on Unity in Concepts and Terminology 1995:279). Ecological sites are land units defined and recognized on the basis of climate, landscape position, and inherent soil properties (texture and mineralogy by depth); typically they are described or named on the basis of the dominant vegetation. Ecological sites are basic land units for resource management and analysis by the Bureau of Land Management and the USDA Natural Resource Conservation Service. The concept is synonymous with "ecological types" of the USDA Forest Service (Society for Range Management, Task Group on Unity in Concepts and Terminology 1995).

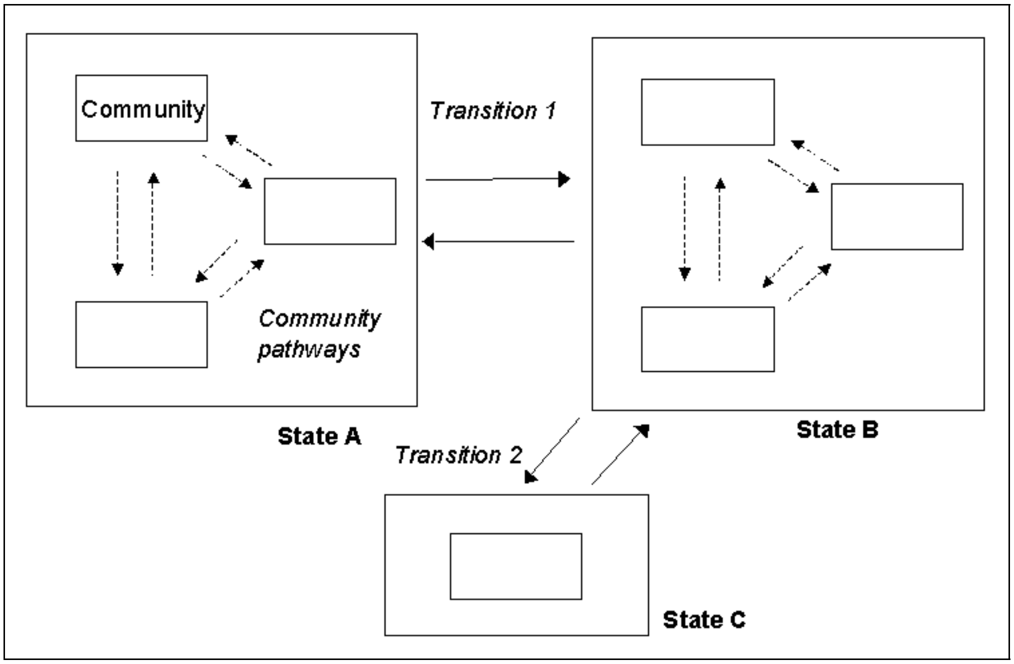


Figure I-5. The general structure of state-and-transition models after Stringham et al. (2001a). The small boxes represent individual plant communities (or community phases) and the dashed arrows between them represent community pathways along which shifts among communities occur. These shifts are reversible through *facilitating* practices and fluctuations in climate. The large boxes containing communities are dynamic states that are distinguished by differences in structure and the rates of ecological processes (such as erosion). The transitions among states (solid arrows) are reversible only through *accelerating* practices (e.g., restoration activities such as exotic species removal/control, fuel reductions, seeding, and/or addition of soil) that can be applied at relatively great financial expense (modified from Bestelmeyer et al. 2003).

Figure I-6 illustrates a state-and-transition model developed as a submodel of the general ecosystem characterization model. Typical of state-and-transition models, this particular example focuses on the soil-vegetation subsystem. Additional submodels would be required to communicate hypotheses concerning interrelated dynamics of other ecosystem components.

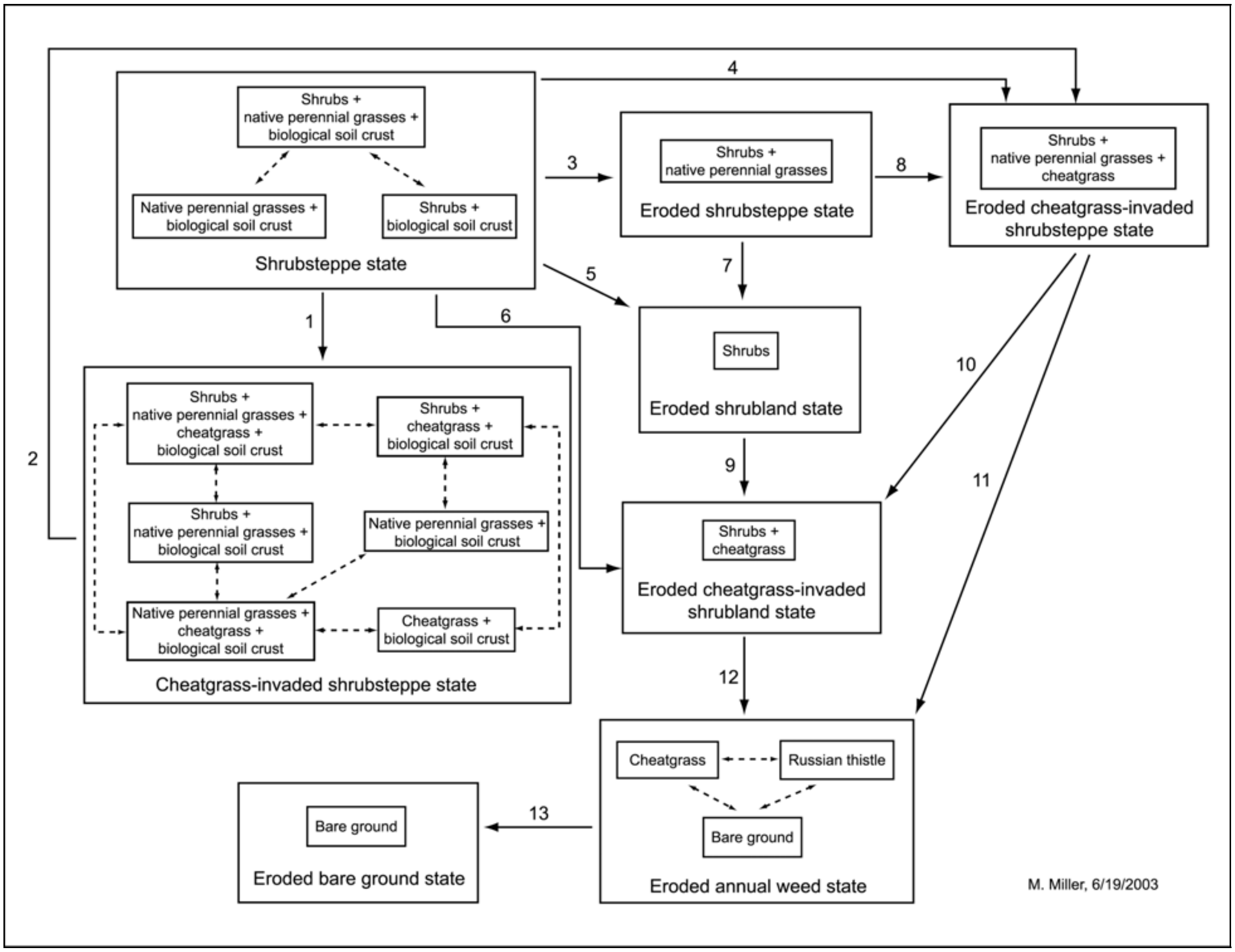


Figure I-6. DRAFT dynamic conceptual model for a generalized shrubsteppe ecological site. Site-specific state-and-transition models for particular ecological sites will require greater differentiation among functional groups (e.g., C_3 vs. C_4 grasses, cyanobacterial vs. lichen crusts, palatable shrubs vs. unpalatable shrubs, fire-tolerant shrubs vs. fire-sensitive shrubs). Most site-specific models will include only a subset of the states and transitions illustrated here. All such models, whether generalized or site-specific, will require accompanying information (narrative or tabular, linked with literature citations to degree possible) describing stressors, natural factors, and ecological processes associated with each of the numbered transitions. In this figure, transitions associated with accelerating (restoration) activities are not depicted. Dynamics associated with the shrubsteppe state represent the desired condition.

As with the general ecosystem model, the state-and-transition model is incomplete without an accompanying literature review. The narrative (accompanied by mechanistic conceptual models as required, see below) should describe processes associated with each of the numbered pathways (within-state dynamics) and/or transitions (among-state dynamics). To the degree possible, information accompanying the diagrammatic model should address the relative probabilities of different transitions and how environmental conditions (e.g., climatic fluctuations) and different anthropogenic stressors affect transition probabilities. Table F-2 illustrates a general tabular format that may be used to summarize material presented in detail in the narrative. Table F-4 provides an example of a tabular approach to summarizing effects of particular stressors on particular types of ecosystem transitions

Table I-2. Sample format for a table describing / summarizing processes associated with dynamics depicted in diagrammatic model.

Transition / pathway	**Description**
1	
2	
...	
n	

Several similar, but less structured, dynamic conceptual models are accessible online at The Nature Conservancy's Ecosystem Management website (http://tnc-ecomanagement.org/).

TNC FOREST MODELS:
http://tnc-ecomanagement.org/Forest/SiteInformation/index.cfm?ItemTypeNumber=2

TNC ARID-LAND MODELS:
http://tnc-ecomanagement.org/Aridlands/SiteInformation/index.cfm?ItemTypeNumber=2

TNC FIRE-ORIENTED MODELS:
http://tnc-ecomanagement.org/Fire/SiteInformation/index.cfm?ItemTypeNumber=2

Mechanistic Models

Next level of detail...where actual indicators and measures are suggested. Anticipatory indicators can be suggested by detailed mechanistic models that focus on *processes* leading to particular (undesirable) ecosystem transitions. Each transition should be characterized by at least one model. One model may be applicable to more than one transition.

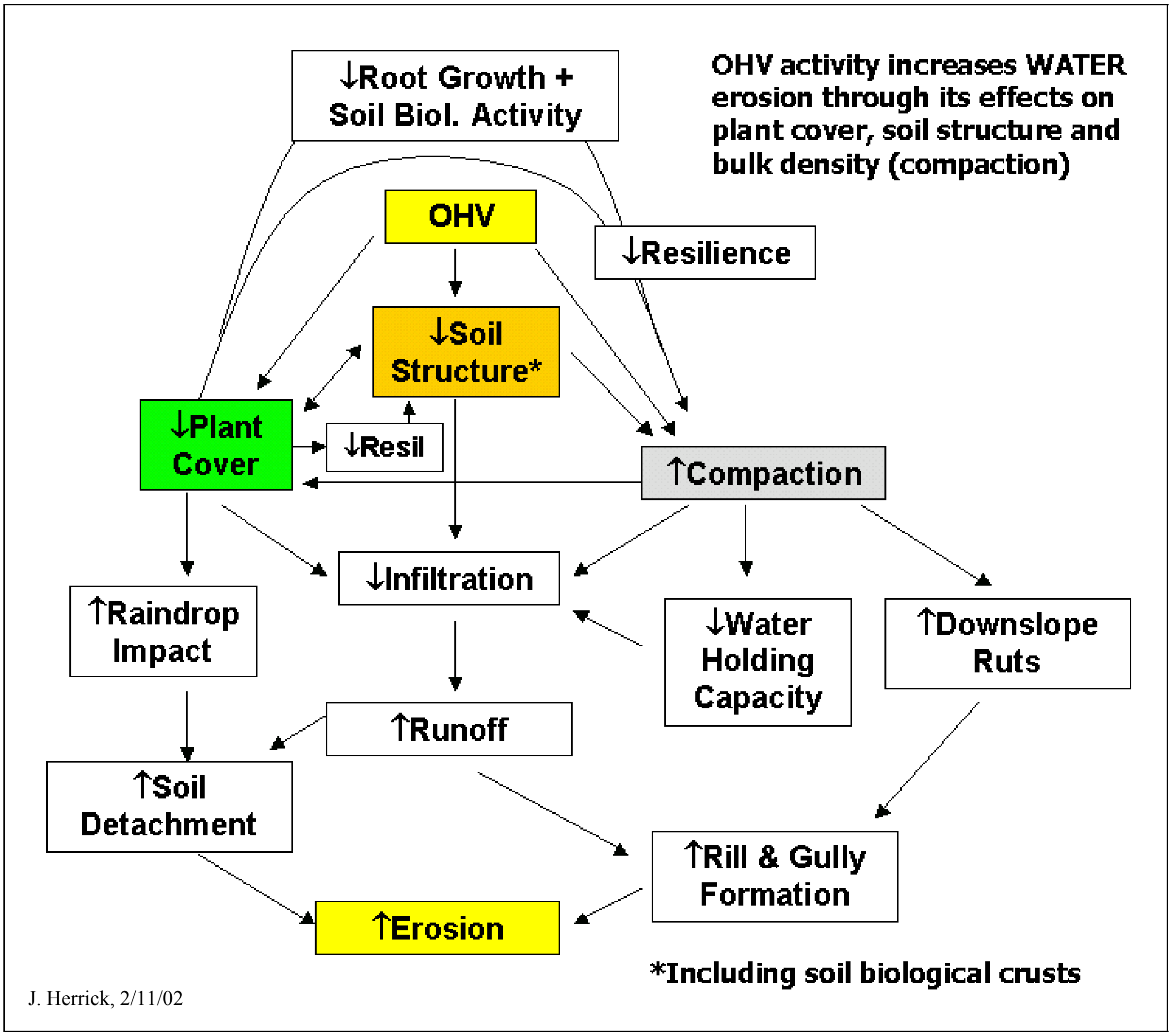


Figure I-7. An example of a conceptual model designed to illustrate the mechanisms by which a stress (OHV activity) affects a particular process (soil erosion) associated with one or more transitions among states.

Literature Cited

Allen, T.F.H. and T.W. Hoekstra. 1992. Toward a unified ecology. Columbia University Press, New York, NY.

Bestelmeyer, B. T., J. R. Brown, K. M. Havstad, R. Alexander, G. Chavez, and J. E. Herrick. 2003. Development and use of state-and-transition models for rangelands. Journal of Range *Management* 56: 114-126.

Bourgeron, P. S., H. C. Humphries, and M. E. Jensen. 2001. Elements of ecological land classifications for ecological assessments. Pages 321-337 in M. E. Jensen and P. S. Bourgeron, eds. *A guidebook for integrated ecological assessments*. Springer-Verlag, New York.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. *The American Naturalist* 148: 1016-1037.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. M. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. *Ecological Applications* 6: 665-691.

De Leo, G. A., and S. Levin. 1997. The multifaceted aspects of ecosystem integrity. *Conservation Ecology* [online]1(1): 3.

Grimm, V., and C. Wissel. 1997. Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. *Oecologia* 109: 323-334.

Harwell, M. A., M. V., T. Young, A. Bartuska, N. Gassman, J. H. Gentile, H. C.C., S. Appelbaum, J. Barko, B. Causey, C. Johnson, A. McLean, R. Smola, P. Templet, and S. Tosini. 1999. A framework for an ecosystem integrity report card. *BioSicence* 49: 543-556.

Jorgensen, S.E. 1986. *Fundamentals of ecological modeling*. Elsevier, New York, NY.

Karr, J. R. 1991. Biological integrity: A long neglected aspect of water resources management. *Ecological Applications* 1: 66-84.

Karr, J. R. 1996. Ecological integrity and ecological health are not the same. Pages 97-109 in P. C. Schultz, ed. *Engineering within ecological constraints*. National Academy Press, Washington, D.C.

Likens, G. 1992. An ecosystem approach: its use and abuse. *Excellence in ecology, book 3*. Ecology Institute, Oldendorf/Luhe, Germany.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications* 9: 1175-1188.

Mulder, B. S., and C. J. Palmer. 1999. Introduction to effectiveness monitoring. Pages 1-19 in B. S. Mulder, B. R. Noon, T. A. Spies, M. G. Raphael, C. J. Palmer, A. R. Olsen, G. H. Reeves, and H. H. Welsh, eds. *The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan. USDA Forest Service Gen. Tech. Rpt. PNW-GTR-437*. USDA Forest Service Pacific Northwest Research Station, Portland, Oregon.

Noon, B. R. 2003. Conceptual issues in monitoring ecological systems. Pages 27-71 in D. E. Busch and J. C. Trexler, eds. *Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives*. Island Press, Washington, D.C.

Osenberg, C.W., R.J. Schmitt, S.J. Holbrook, K.E. Abu-Saba, and A.R. Flegal. 1994. Detection of environmental impacts: Natural variability, effect size, and power analysis. *Ecological Applications* 4: 16-30.

Richter, B. D., and H. E. Richter. 2000. Precribing flood regimes to sustain riparian ecosystems along meandering rivers. *Conservation Biology* 14: 1467-1478.

Rosgen, D. L. 1994. A classification of natural rivers. *Catena* 22: 169-199.

Rowe, J. S., and J. V. Barnes. 1994. Geo-ecosystems and bio-ecosystems. *Ecological Society of America Bulletin* 75: 40-41.

Scheffer, M., S. Carpenter, J. A. Foley, C. Folke, and B. Walker. 2001. Catastrophic shifts in ecosystems. *Nature* 413: 591-596.

Society for Range Management, Task Group on Unity in Concepts and Terminology. 1995. New concepts for assessment of rangeland condition. *Journal of Range Management* 48: 271-282.

Starfield, A.M. and A.L. Bleloch. 1986. *Building models for conservation and wildlife management*. Macmillan Publishing Co., New York, NY.

Stringham, T. K., W. C. Krueger, and P. L. Shaver. 2001a. *States, transitions, and thresholds: Further refinement for rangeland applications*. Agricultural Experiment Station, Oregon State University, Corvallis, OR. [Available online at http://www.ftw.nrcs.usda.gov/glti/pubs.html.]

Stringham, T. K., W. C. Krueger, and D. R. Thomas. 2001b. Application of non-equilibrium ecology to rangeland riparian zones. *Journal of Range Management* 54: 210-217.

Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: Using the past to manage for the future. *Ecological Applications* 9: 1189-1206.

Turner, M.G. and R.V. O'Neill. 1994. Exploring aggregation in space and time. *In* Jones, C.G. and J.H. Lawton, eds. *Linking Species and Ecosystems*. Chapman and Hall, New York, NY.

Table I-3. Primary functions and attributes associated with natural components of arid-semiarid ecosystems of the NCPN. Components are organized in relation to the four interactive controls of ecosystem structure and function. Components with the greatest influence over primary ecosystem processes of water capture and retention, nutrient cycling, and energy capture in arid-semiarid NCPN ecosystems (in the absence of anthropogenic stressors) are underlined in bold.

INTERACTIVE CONTROLS*	COMPONENTS		PRIMARY ECOSYSTEM FUNCTIONS	ATTRIBUTES
Local atmospheric resources and conditions	**Precipitation**		Water inputs; driver of water-limited ecosystem and population processes (e.g., nutrient cycling, C and N fixation, seed germination); erosive force for detachment, entrainment, and overland redistribution and export of soil, litter, and propagules; driver of fire disturbances due to effects of interannual variability on fuel production and flammability; enhance resistance and resilience of biotic and biotically structured ecosystem components (e.g., soil) to natural disturbances and anthropogenic stressors.	Seasonality; quantity; intensity (amt. per event and per unit time), duration, temporal frequency; temporal variability (among seasons, within seasons, among years), spatial variability, form (rain vs. snow).
	Wind		Soil, litter, and propagule redistribution and export (transfer among patches and among systems); effects on ecosystem-atmosphere gas-exchange (CO_2 intake and evapotranspiration); energy-balance modification (transfer of sensible and latent heat).	Average sustained and peak velocities and direction (and frequency-magnitude distributions of these by season), seasonal and diurnal variability, spatial variability.
	Radiation		Energy inputs for photosynthesis and heat; effects on ecosystem-atmosphere gas-exchange (CO_2 uptake and evapotranspiration).	Maximum, minimum, and average values by season (heat), spectral characteristics, intensity; temporal variability (seasonal and diurnal), spatial variability (horizontally and vertically).
	CO_2		Carbon inputs.	Atmospheric concentration
	Dust & other airborne constituents		Mineral nutrient inputs.	Quantity, chemical composition, temporal distribution (seasonality), spatial distribution.
Disturbance regime	**Episodic climatic events**	**Drought**	Drives change in ecosystem structure and function (1) by altering competitive relations and inducing selective, potentially widespread, mortality – resulting in persistent dominance shifts among vegetative functional groups; (2) by affecting resistance and resilience of biotic and biotically structured ecosystem components (e.g., soil) to other natural disturbances (e.g., subsequent extreme precipitation events or wind storms) and anthropogenic stressors; and (3) by altering the likelihood of other natural disturbances such as wind storms or fire.	Seasonality, intensity, duration, frequency, timing in relation to extreme precip. and wind events.
		Extreme precip. events / floods	Drives change in ecosystem structure and function (1) by inducing selective establishment episodes (or less commonly, selective mortality) of vegetative functional groups – resulting in persistent dominance shifts; and (2) due to extreme erosive forces for detachment, entrainment, and redistribution and export of soil and soil resources, potentially inducing geomorphic change.	Seasonality, intensity, duration, frequency, timing in relation to drought and the amount of time required for biotic and biotically structured ecosystem components and functions to recover from drought.
		Wind storms	Drives change in ecosystem structure and function due to extreme erosive forces for detachment, entrainment, and redistribution and export of soil and soil resources.	Seasonality, intensity, duration, frequency, timing in relation to drought and the amount of time required for biotic and biotically structured ecosystem components and functions to recover from drought.
	Fire		Drives change in ecosystem structure and function by (1) directly altering vegetation structure (differential resistance and resilience to fire), including spatial heterogeneity, (2) altering the forms, bioavailability, and spatiotemporal distribution of soil resources, (3) increasing exposure and erosion susceptibility of soil and soil resources and reducing ecosystem capacity to retain soil resources (including water).	Intensity, spatial extent and pattern, frequency, timing in relation to other disturbances such as extreme precipitation and wind events.
	Herbivory		Drives change in ecosystem structure and function by (1) altering competitive relations among palatable and unpalatable plant taxa, (2) altering vegetation resistance and resilience to drought, other disturbances, and stressors, and (3) potentially affecting primary productivity and litter deposition. In combination, these can alter functional group structure, including spatial heterogeneity, and ecosystem capacity to capture and retain soil resources. Defecation (the eventual consequence of herbivory) further alters the spatiotemporal distribution of resources.	Intensity, selectivity, spatial extent and pattern, frequency, timing in relation to other disturbances such as drought and the amount of time required for biotic and biotically structured ecosystem components and functions to recover from drought.
	Digging / burrowing		Alters soil structure and function (creation of macropores potentially increase water capture and retention), alters spatiotemporal distribution of soil resources, generates patch structure / heterogeneity, potentially alters structure of vegetative functional groups due to resource alteration and creation of establishment opportunities.	Spatial distribution and extent, frequency, depth, timing in relation to other disturbances such as extreme wind and precipitation events.
	Trampling		Destabilizes soil and decreases resistance of soil to erosion and redistribution by wind and water; compacts soil (alters soil structure and function), alters structure and function of biological soil crusts; alters vegetation structure due to trampling of vegetation or via effects of altered soil function on resistance and resilience of vegetation to drought. Together, these decrease ecosystem capacity to capture and retain soil resources.	Intensity, spatial extent and pattern, frequency, timing in relation to other disturbances such as extreme wind and precipitation events, drought, and the amount of time required for biotic and biotically structured ecosystem components and functions to recover from drought.

Table I-3 continued.

INTERACTIVE CONTROLS	COMPONENTS			PRIMARY ECOSYSTEM FUNCTIONS	ATTRIBUTES
Biotic functional groups	Predators			Regulation of (or response to) prey populations, including granivores and herbivores. May also impact ecosystem structure and function by digging / burrowing (see above).	Composition, quantity, population structure and dynamics; physiological condition.
	Herbivores			See Herbivory, above. May also impact ecosystem structure and function by digging / burrowing (see above).	Composition, quantity, population structure and dynamics; physiological condition.
	Granivores			Alteration of vegetation structure (composition and spatial heterogeneity) due to selective collection, consumption, burial, and redistribution of propagules. May also impact ecosystem structure and function by digging / burrowing (see above).	Composition, quantity, population structure and dynamics; physiological condition.
	Small trees **Shrubs** **Dwarf shrubs** **Perennial grasses**			Energy capture and conversion, biomass production, litter deposition (soil protection and inputs to nutrient cycles), nutrient retention (intraplant cycling), environmental modification (reducing soil temperatures and evaporative rates via shading and litter deposition; generating resource heterogeneity via uptake, litter deposition, and capture of airborne and windborne materials), obstruction to wind and overland water flow (reducing erosive energy and enhancing capture and retention of soil resources), rainfall interception and redistribution via stemflow (reducing erosive energy and enhancing capture and retention of soil resources). In combination, these functions contribute to resistance / resilience of soil functions to disturbance by trampling and erosive forces of wind and water. Provide fuel for fire and habitat structure for vertebrates and invertebrates.	Composition, quantity (cover and biomass), population structure and dynamics, vertical structure, spatial distribution / heterogeneity, photosynthetic pathway, leaf longevity, litter quantity and quality (e.g., C:N), flammability, productivity; physiological activity and condition; resistance & resilience of structure and function to dominant natural disturbances and anthropogenic stressors.
	<< The Soil Continuum >>	**Biological soil crusts (photoautotrophs)**		Soil stabilization and soil-surface protection; energy capture and conversion; nutrient capture, retention, and cycling (N fixation, capture of airborne minerals in dust); obstruction to overland water flow (increased surface roughness enhances capture and retention of soil resources); environmental modification (albedo & soil temperature,); soil-temperature increases (decreased albedo); habitat creation (due to long-term soil stabilization).	Composition, quantity (cover and biomass), spatial distribution and contiguity, microtopographic heterogeneity / surface roughness; physiological activity and condition; productivity; resistance & resilience of structure and function to dominant natural disturbances and anthropogenic stressors.
		Roots		Soil stabilization, nutrient and water acquisition and transport, water redistribution in soil profile, organic-matter inputs (exudates & tissues), macropore creation, rhizospere acidification (release CO_2 and organic acids).	Morphology, density, horizontal and vertical distribution, spatial and temporal patterns of physiological activity, productivity.
		Soil biota (heterotrophs)		Litter decomposition and nutrient cycling, N fixation, symbiotic relations with vascular plants (symbiotic enhancement of nutrient and water delivery to vascular plants may increase resistance / resilience of these plants to drought or other disturbances).	Composition, quantity (biomass), spatial distribution vertically and horizontally, temporal distribution, spatial and temporal patterns of physiological activity, productivity; resistance & resilience of structure and function to dominant natural disturbances and anthropogenic stressors.
Soil resources and conditions		**"Soil"**	**Soil mineral matrix** **Soil organic matter** **Soil water** **Soil air**	Nutrient storage, supply, and cycling; water storage and supply; medium for plant growth; habitat for soil biota involved in nutrient cycling; positive effects on resistance / resilience of vegetative functional groups to drought, herbivory, and trampling.	Inherent properties (relatively insensitive to change): Mineralogy and texture by depth, spatial heterogeneity in these properties, depth. Dynamic properties (subject to change): Aggregate stability and bulk density (structure), organic-matter quantity and quality (e.g., C:N), depth (often considered an inherent property, but subject to change over decadal time scales), erosion rate, infiltration rate, biotic activity, surface crusting (biotic or physicochemical), surface roughness, spatial heterogeneity of these properties, resistance & resilience of structure and function to dominant natural disturbances and anthropogenic stressors.
	Soil temperature			Regulates physiological activity of autotrophic and heterotrophic soil biota, including roots.	Maximum, minimum, and average values by season; temporal variability (seasonal and diurnal), spatial variability (horizontally and vertically).

Primary sources: Whitford (2002), Herrick et al. (2002), Belnap and Lange (2001), Ehleringer et al. (2000), Seybold et al. (1999), Whisenant (1999), and Ludwig et al. (1997).
* Interactive controls are constrained by the five state factors—(1) global/regional atmospheric resources and conditions, (2) topography, (3) parent material, (4) potential biota, and (5) time (Jenny 1980, Chapin et al. 1996).

Table I-4. Potential effects of selected anthropogenic stressors on key components, functions, and transition probabilities of arid-semiarid NCPN ecosystems.

<table>
<tr><th rowspan="2">Stressors</th><th rowspan="2">Stress mechanisms</th><th rowspan="2">Potential effects on ecosystem components, attributes and key ecosystem functions (energy flow, nutrient capture and retention, water capture and retention)</th><th colspan="5">Increased transition probabilities*</th></tr>
<tr><th>$T_{1.2}$</th><th>$T_{1.3}$</th><th>$T_{1.4}$</th><th>$T_{2.4}$</th><th>$T_{3.4}$</th></tr>
<tr><td rowspan="2">Park users</td><td>Trampling of soil and vegetation</td><td>Damaged biological soil crusts, decreased N fixation by biological crusts, decreased soil-surface roughness, enhanced recruitment opportunities for exotic plants, altered vegetation structure, decreased soil protection by biological crusts, decreased soil aggregate stability, decreased soil stability, decreased resistance of soil to erosion by wind and water, increased bulk density, decreased infiltration, increased overland flow of water, decreased soil-water availability for plant growth, soil biotic activity, and nutrient cycling; decreased root growth and soil-organic-matter inputs, decreased plant growth, decreased resistance and resilience of plants to drought, increased redistribution and export of soil, litter, nutrients, and water; decreased capacity of ecosystem to capture and retain soil resources; multiple cascading effects due to feedbacks among soil functions, soil-resource retention, resource heterogeneity, and vegetation structure.</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Introduction of exotic plants</td><td>See exotics, below.</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td rowspan="4">Livestock</td><td>Trampling of soil and vegetation</td><td>See trampling, above.</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Excessive herbivory</td><td>Altered competitive relations of plants, altered vegetation structure (e.g., dominance shift from perennial grasses to unpalatable shrubs and/or from palatable native plants to unpalatable exotics), reduced plant canopy cover, reduced plant-canopy protection of soil, reduced vegetative obstruction of overland water flow, reduced capture and retention of soil resources, reduced litter deposition and litter-protection of soil, reduced soil-organic-matter inputs, reduced soil aggregate stability, decreased resistance and resilience of soil to trampling, decreased root growth, decreased resistance and resilience of grazed plants to drought; multiple cascading effects due to feedbacks among vegetation structure, soil-resource retention, resource heterogeneity, and soil functions.</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>Defecation</td><td>Nutrient losses (N volatilization), nutrient immobilization in dung pats, increased spatial and temporal heterogeneity of nutrients, eventual alteration of vegetation structure, facilitation of exotic-plant invasion where nutrients locally enriched (see exotics, below).</td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>Introduction of exotic plants</td><td>See exotics, below.</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td rowspan="3">Exotic plants</td><td>Competition with native plants</td><td>Altered vegetation structure, eventual alteration of soil-resource dynamics and/or heterogeneity due to vegetation-soil feedbacks.</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>Altered soil-resource dynamics</td><td>Altered nutrient dynamics (e.g., exotic characterized by different tissue chemistry, and/or by different spatiotemporal patterns of nutrient uptake and litter deposition than native plants), altered soil-water dynamics (e.g., exotic characterized by different spatiotemporal patterns of water use than native plants), eventual alteration of vegetation structure due to soil-vegetation feedbacks.</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>Altered disturbance regime</td><td>Increased frequency and extent of fire (facilitated by increased quantity, flammability, and/or spatial continuity of fuels); eventual alterations of vegetation structure and soil-resource availability due to strong feedbacks among fire, vegetation structure, and resource availability.</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td rowspan="3">Adjacent land-use activities</td><td>Trespass livestock</td><td>See livestock, above.</td><td colspan="5">See livestock, above.</td></tr>
<tr><td>Introduction of exotic plants</td><td>See exotics, above.</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
<tr><td>Accelerated transfers of soil, nutrients, and water</td><td>Soil-resource enrichment, eventual alteration of vegetation structure, facilitation of exotic-plant invasion where resources enriched (see exotics, above), increased overland water flow, increased redistribution and export of soil and nutrients.</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td rowspan="2">Air pollutants</td><td>Nitrogen deposition</td><td>Soil-resource enrichment, eventual alteration of vegetation structure, facilitation of exotic-plant invasion (see exotics, above).</td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>Ozone</td><td>Altered competitive relations between ozone-sensitive and ozone-tolerant plants, altered vegetation structure</td><td></td><td>X</td><td></td><td></td><td>X</td></tr>
</table>

*Transition notation: $T_{1.2}$ = transition from State 1 to State 2.
State 1: structure and function unaltered by anthropogenic stressors.
State 2: irreversibly altered soil-resource regime.
State 3: irreversibly altered functional-group structure.
State 4: irreversibly altered soil-resource regime and functional-group structure

Appendix J. Glossary of Key Terms and Concepts

Prepared by:

Mark Miller, USGS-BRD

9 August 2003 WORKING DRAFT

Adaptive management – a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form—"active" adaptive management—employs management programs that are designed to experimentally compare selected policies or practices, by implementing management actions explicitly designed to generate information useful for evaluating alternative hypotheses about the system being managed (http://science.nature.nps.gov/im/monitor/Glossary.htm).

Adaptive monitoring design – an iterative process that refines the specifications for monitoring over time as a result of experience in implementing a monitoring program, assessing results, and interacting with users (Ringold et al. 1999).

Attributes – any living or nonliving feature or process of the environment that can be measured or estimated and that provide insights into the state of the ecosystem. The term **Indicator** is reserved for a subset of attributes that is particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003; http://science.nature.nps.gov/im/monitor/Glossary.htm).

Degradation – an anthropogenic reduction in the capacity of a particular ecosystem or ecosystem component to perform desired ecosystem functions (e.g., degraded capacity for conserving soil and water resources). Human actions may degrade desired ecosystem functions directly, or they may do so indirectly by damaging the capacity of ecosystem functions to resist or recover from natural disturbances and/or anthropogenic stressors (derived from concepts of Herrick et al. 1995, Ludwig et al. 1997, Whisenant 1999, Archer and Stokes 2000, and Whitford 2002).

Disturbance: "...any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett 1985:7). In relation to monitoring, disturbances are considered to be ecological factors that are within the evolutionary history of the ecosystem (e.g., drought). These are differentiated from anthropogenic factors (*stressors,* below) that are outside the range of disturbances naturally experienced by the ecosystem (Whitford 2002).

Disturbance stimuli – nonlethal, human-caused events that change an animal's behaviour from patterns occurring without human influence; analogous to predation risk (Frid and Dill 2002).

Driver – a natural agent responsible for causing temporal changes or variability in quantitative measures of structural and functional attributes of ecosystems.

Dynamic soil properties – soil properties that vary in relation to management activities, climatic fluctuations, or natural disturbances (e.g., bulk density, infiltration capacity, soil-surface roughness, organic-matter content, soil aggregate stability, biological soil crust cover and composition).

Ecological indicator – see *indicator*.

Ecological integrity – a concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self-renewal. Ecological integrity implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes (http://science.nature.nps.gov/im/monitor/Glossary.htm).

Ecological site – a kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management (Society for Range Management Task Group on Unity in Concepts and Terminology 1995:279).

Ecological sustainability – the tendency of a system or process to be maintained or preserved over time without loss or decline (Dale et al. 2000:642).

Ecosystem – a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries (Likens 1992, cited by Christensen et al. 1996:670).

Ecosystem engineers – organisms that directly or indirectly modulate the availability of resources to other species by causing physical state changes in biotic or abiotic materials, thereby modifying, maintaining, and/or creating habitats (Jones et al. 1994).

Ecosystem functioning – the flow of energy and materials through the arrangement of biotic and abiotic components of an ecosystem. Includes many ecosystem processes such as primary production, trophic transfer from plants to animals, nutrient cycling, water dynamics and heat transfer. In a broad sense, ecosystem functioning includes two components: ecosystem resource dynamics and ecosystem stability (Díaz and Cabido 2001).

Ecosystem health – a metaphor pertaining to the assessment and monitoring of ecosystem structure, function, and resilience in relation to the notion of ecosystem “sustainability” (following Rapport 1998 and Costanza et al. 1998). A healthy ecosystem is sustainable (see *Sustainable ecosystem*, below).

Ecosystem integrity – see *ecological integrity*.

Ecosystem management – the process of land-use decision making and land-management practice that takes into account the full suite of organisms and processes that characterize and comprise the ecosystem and is based on the best understanding currently available as to how the ecosystem works. Ecosystem management includes a primary goal of sustainability of ecosystem structure and function, recognition that ecosystems are spatially and temporally dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity (Dale et al. 2000:642).

Ecosystem sustainability – see *sustainable ecosystem*.

Endpoints – Ecosystem attributes of ecological and/or societal importance (Harwell et al. 1999). Endpoints may or may not be indicators of overall ecosystem condition (also referred to as *assessment endpoints*).

Focal ecosystems – ecosystems that play significant functional roles in landscapes by their disproportionate contribution to the transfer of matter and energy, or by their disproportionate contribution to landscape-level biodiversity (Miller; adapted from definition of *focal species*).

Focal species / organisms – species / organisms that play significant functional roles in ecological systems by their disproportionate contribution to the transfer of matter and energy, by structuring the environment and creating opportunities for additional species / organisms, or by exercising control over competitive dominants and thereby promoting increased biological diversity (derived from Noon 2003:37). [Encompasses concepts of keystone species, umbrella species, and ecosystem engineers.]

Functional groups – groups of species that have similar effects on ecosystem processes (Chapin et al. 1996) – frequently applied interchangeably with *functional types*.

Functional types –sets of organisms sharing similar responses to environmental factors such as temperature, resource availability, and disturbance (= functional *response* types) and/or similar effects on ecosystem functions such as productivity, nutrient cycling, flammability, and resistance / resilience (= functional *effect* types) (Díaz and Cabido 2001).

Hydrologic function (upland systems) – capacity of a site to capture, store, and safely release water from rainfall, run-on, and snowmelt, to resist a reduction in this capacity, and to recover this capacity following degradation (Pellant et al. 2000).

Hydrologic function (lotic and lentic systems) – capacity of an area to:

- dissipate energies associated with (1) high stream flow (lotic); or (2) wind action, wave action, and overland flow (lentic); thereby reducing erosion and improving water quality;
- filter sediment, capture bedload, and aid floodplain development;
- improve flood-water retention and groundwater recharge;
- develop root masses that stabilize streambanks against cutting action;
- develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses;
- support greater biodiversity

  (from Prichard et al. 1998, 1999)

Indicator (general use of term) – a term reserved for a subset of environmental attributes that is particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003; http://science.nature.nps.gov/im/monitor/Glossary.htm).

Indicators of ecosystem health (specific use of term) – measurable attributes of the environment (biotic or abiotic) that provide insights regarding (1) the functional status of one or more key ecosystem processes, (2) the status of ecosystem properties that are clearly related to these ecosystem processes, and/or (3) the capacity of ecosystem processes or properties to resist or recover from natural disturbances and/or anthropogenic stressors (modified from Whitford 1998). In the context of ecosystem health, key ecosystem processes and properties are those that are most closely associated with the capacity of the ecosystem to maintain its characteristic structural and functional attributes over time (including natural variability).

Inherent soil properties – soil properties that are relatively unaffected by management activities, climatic fluctuations, and natural disturbances (e.g., texture, color, depth, mineralogy, horizonation).

Landscape – a spatially structured mosaic of different types of ecosystems interconnected by flows of materials (e.g., water, sediments), energy, and organisms.

Landscape diversity – the number of ecosystem types and their spatial distribution (Chapin et al. 1998).

Measures – the specific variables used to quantify the condition or state of an Attribute or Indicator (or vital sign). These are specified in definitive sampling protocols. For example, stream acidity may be the indicator, while pH units are the measure (from NPS Inventory and Monitoring website, http://science.nature.nps.gov/im/monitor/vsm.htm#Definitions).

Rangeland – land on which the indigenous vegetation is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. Rangelands include natural grasslands, savannas, shrublands, many deserts, tundra, alpine communities, marshes, and wet meadows (Society for Range Management 1999). For purposes of this document, we further include pinyon-juniper woodlands and oak woodlands in this definition.

Resilience – the capacity of a particular ecological attribute or process to recover to its former reference state or dynamic after exposure to a temporary disturbance and/or stressor (adapted from Grimm and Wissel 1997). Resilience is a dynamic property that varies in relation to environmental conditions (Scheffer et al. 2001).

Resistance – the capacity of a particular ecological attribute or process to remain essentially unchanged from its reference state or dynamic despite exposure to a disturbance and/or stressor (adapted from Grimm and Wissel 1997). Resistance is a dynamic property that varies in relation to environmental conditions (Scheffer et al. 2001).

Soil degradation – a decline in soil quality (i.e., decline in a soil's capacity to perform desired ecological functions)

Soil resilience – the capacity of a soil to recover its functional and structural integrity after a disturbance, as characterized by two components: (1) the rate of recovery and (2) the degree of recovery (Herrick and

Wander 1998, Seybold et al. 1999). For a particular soil, resilience depends on the spatial scale of the disturbance and the temporal scale of evaluation, and it must be described with respect to the type and degree of disturbance (Seybold et al. 1999). In general, soil resilience is inversely related to climatic aridity.

Soil resistance – the capacity of a soil to continue to function without change throughout a disturbance (Herrick and Wander 1998, Seybold et al. 1999). For a particular soil, resistance must be defined in relation to a particular type and degree of disturbance (Seybold et al. 1999).

Soil quality – the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al. 1997:6). From an NPS perspective, soil quality is defined by a soil's capacity to perform the following ecological functions: (a) regulate hydrologic processes; (b) capture, retain, and cycle mineral nutrients; (c) support characteristic native communities of plants and animals. Soil quality can be regarded as having (1) an inherent component defined by the soil's inherent soil properties as determined by the five factors of soil formation, and (2) a dynamic component defined by the change in soil function that is influenced by human use and management of the soil (Seybold et al. 1999).

Soil / site stability – the capacity of a site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (Pellant et al. 2000).

State – as applied to state-and-transition models, a *state* is defined as "a recognizable, resistant and resilient complex of two components, the soil [or geomorphic] base and the vegetation structure" (Stringham et al. 2003:109). These two ecosystem components interactively determine the functional status of the primary ecosystem processes of energy flow, nutrient cycling, and hydrology. States are dynamic and "... are distinguished from other states by relatively large differences in plant functional groups and ecosystem processes [including disturbance and hydrologic regimes] and, consequently, in vegetation structure, biodiversity, and management requirements" (Bestelmeyer et al. 2003:116). (Also see *threshold* and *transition*.)

Stressor: any physical, chemical, or biological entity or process that can induce an adverse response (modified from EMAP Master Glossary, http://www.epa.gov/emap/html/pubs/docs/resdocs/mglossary.html). For purposes of monitoring, stressors are considered to be anthropogenic factors that are outside the range of disturbances naturally experienced by the ecosystem (Whitford 2002). Compare with *Disturbance*, above.

Sustainable ecosystem – an ecosystem "...that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, and rates of biogeochemical cycling" (Chapin et al. 1996:1016).

Threshold – as applied to state-and-transition models, a *threshold* is a point "...in space and time at which one or more of the primary ecological processes responsible for maintaining the sustained [dynamic] equilibrium of the state degrades beyond the point of self-repair. These processes must be actively restored before the return to the previous state is possible. In the absence of active restoration, a new state ... is formed" (Stringham et al. 2003:109). Thresholds are defined in terms of the functional status of key ecosystem processes and are crossed when capacities for resistance and resilience are exceeded. (Also see *state* and *transition*.)

Transition – as applied to state-and-transition models, a *transition* is a trajectory of change that is precipitated by natural events and/or management actions which degrade the integrity of one or more of the primary ecological processes responsible for maintaining the dynamic equilibrium of the state. Transitions are vectors of system change that will lead to a new state without abatement of the stressor(s) and/or disturbance(s) prior to exceeding the system's capacities for resistance and resilience (adapted from Stringham et al. 2003). (Also see *state* and *threshold*.)

Vital signs – a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes) (from NPS Inventory and Monitoring website, http://science.nature.nps.gov/im/monitor/vsm.htm#Definitions).

LITERATURE CITED

Archer, S., and C. Stokes. 2000. Stress, disturbance and change in rangeland ecosystems. Pages 17-38 in O. Arnalds and S. Archer, eds. *Rangeland desertification*. Kluwer, Dordrecht.

Bestelmeyer, B. T., J. R. Brown, K. M. Havstad, R. Alexander, G. Chavez, and J. E. Herrick. 2003. Development and use of state-and-transition models for rangelands. *Journal of Range Management* 56: 114-126.

Chapin, F. S., III, M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. *The American Naturalist* 148: 1016-1037.

Chapin, F. S., III, O. E. Sala, I. C. Burke, J. P. Grime, D. U. Hooper, W. K. Lauenroth, A. Lombard, H. A. Mooney, A. R. Mosier, S. Naeem, S. W. Pacala, J. Roy, W. L. Steffen, and D. Tilman. 1998. Ecosystem consequences of changing biodiversity. *Bioscience* 48: 45-52.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. M. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. *Ecological Applications* 6: 665-691.

Costanza, R., M. Mageau, B. Norton, and B. C. Patten. 1998. What is sustainability? Pages 231-239 in D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, eds. *Ecosystem health*. Blackwell Science, Malden, MA.

Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2000. Ecological principles and guidelines for managing the use of land. *Ecological Applications* 10: 639-670.

Díaz, S., and M. Cabido. 2001. Vive la différence: plant functional diversity matters to ecosystem processes. *Trends in Ecology & Evolution* 16: 646-655.

Frid, A., and L. Dill. 2002. Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology* 6: 11. [online] URL: http://www.consecol.org/vol6/iss1/art11

Grimm, V., and C. Wissel. 1997. Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. *Oecologia* 109: 323-334.

Harwell, M. A., V. Myers, T. Young, A. Bartuska, N. Gassman, J. H. Gentile, C. C. Harwell, S. Appelbaum, J. Barko, B. Causey, C. Johnson, A. McLean, R. Smola, P. Templet, and S. Tosini. 1999. A framework for an ecosystem integrity report card. *BioSicence* 49: 543-556.

Herrick, J. E., and M. M. Wander. 1998. Relationships between soil organic carbon and soil quality in cropped and rangeland soils: the importance of distribution, composition and soil biological activity. Pages 405-425 in R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, eds. *Soil Processes and the Carbon Cycle*. CRC Press, Boca Raton.

Herrick, J. E., W. G. Whitford, A. G. DeSoyza, and J. W. Van Zee. 1995. Soil and vegetation indicators for assessment of rangeland ecological condition. Pages 157-166 in C. Aguirre-Bravo, ed. *North American workshop on monitoring for ecological assessment of terrestrial and aquatic ecosystems. 1995, September 18-22; Monticello, Texcoco, México. Gen. Tech. Rep. RM-GTR-284*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO.

Karlen, D. L., M. J. Mausbach, J. W. Doran, R. G. Cline, R. F. Harris, and G. E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation. *Soil Science Society of America Journal* 61: 4-10.

Likens, G. 1992. An ecosystem approach: its use and abuse. *Excellence in ecology, book 3*. Ecology Institute, Oldendorf/Luhe, Germany.

Ludwig, J. A., D. J. Tongway, D. O. Freudenberger, J. C. Noble, and K. C. Hodgkinson, eds. 1997. *Landscape ecology, function and management: principles from Australia's rangelands*. CSIRO Publishing, Collingwood, VIC, Australia.

Noon, B. R. 2003. Conceptual issues in monitoring ecological systems. Pages 27-71 in D. E. Busch and J. C. Trexler, eds. *Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives*. Island Press, Washington, D.C.

Pellant, M., P. L. Shaver, D. A. Pyke, and J. E. Herrick. 2000. *Interpreting indicators of rangeland health. Version 3. Interagency technical reference TR-1734-6*. U.S. Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. 188 pp.

Prichard, D., J. Anderson, C. Correll, J. Fogg, K. Gebhardt, R. Krapf, S. Leonard, B. Mitchell, J. Staats. 1998. *Riparian area management : A user guide to assessing proper functioning condition and the supporting science for lotic areas. Interagency technical reference 1737-15.* U.S. Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. 126 pp.

Prichard, D., F. Berg, W. Hagenbuck, R. Krapf, R. Leinard, S. Leonard, M. Manning, C. Noble, and J. Staats. 1999. *Riparian area management : A user guide to assessing proper functioning condition and the supporting science for lentic areas. Interagency technical reference 1737-16*. U.S.

Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. 109 pp.

Rapport, D. J. 1998. Defining ecosystem health. Pages 18-33 in D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, eds. *Ecosystem health*. Blackwell Science, Malden, MA.

Ringold, P. L., B. Mulder, J. Alegria, R. L. Czaplewski, T. Tolle, and K. Burnett. 1999. Establishing a regional monitoring strategy: the Pacific Northwest Forest Plan. *Environmental Management* 23: 179-192.

Seybold, C. A., J. E. Herrick, and J. J. Brejda. 1999. Soil resilience: A fundamental component of soil quality. *Soil Science* 164: 224-234.

Society for Range Management. 1999. *A glossary of terms used in range management*. Society for Range Management, Denver, CO. 20 pp.

Stringham, T. K., W. C. Krueger, and P. L. Shaver. 2003. State and transition modeling: An ecological process approach. *Journal of Range Management* 56: 106-113.

Whisenant, S. G. 1999. *Repairing damaged wildlands: a process-oriented, landscape-scale approach*. Cambridge University Press, Cambridge.

White, P. S., and S. T. A. Pickett. 1985. Natural disturbance and patch dynamics: An introduction. Pages 3-13 in S. T. A. Pickett and P. S. White, eds. *The ecology of natural disturbance and patch dynamics*. Academic Press, San Diego.

Whitford, W. G. 1998. Validation of indicators. Pages 205-209 in D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, eds. *Ecosystem health*. Blackwell Science, Malden, MA.

Whitford, W. G. 2002. *Ecology of desert systems*. Academic Press, San Diego. 343 pp.

Appendix K. Geoindicators Scoping Report for Arches National Park, Canyonlands National Park, Capitol Reef National Park, and Natural Bridges National Monument

[This appendix presents the body of the geoindicators scoping report. Of the several appendices that accompanied the original geoindicators report, only one is included here (Appendix I. Recommendations Table). Other appendices are available upon request from the NCPN.]

Geoindicators Scoping Report for
Arches National Park, Canyonlands National Park, Capitol Reef National Park, and Natural Bridges National Monument

Strategic Planning Goal Ib4

June 3-5, 2002
Moab, Utah

Compiled by Andy Pearce
December 2002

Contents

Scoping Summary

Introduction
From June 3-5, 2002, staff of the National Park Service, Utah Geological Survey, U.S. Geological Survey, Bureau of Land Management, Northern Arizona University, and Brigham Young University participated in a geoindicators scoping meeting in Moab, Utah for four National Park Service units in southeastern Utah. The four parks were Arches National Park (ARCH), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), and Natural Bridges National Monument (NABR).

Purpose of meeting
The purpose of the meeting was to bring together park staff, geoscientists, and other resource specialists to address the issue of human influences on geologic processes in the four park areas. The group used collective knowledge of the four parks' geology and natural resources to identify the geologic processes active in the parks, to identify the human activities affecting those processes, and to develop recommendations for long-term monitoring of geoindicators in conjunction with park Vital Signs monitoring.

In addition, the Northern Colorado Vital Signs Network is coming on-line in fiscal year 2002 and will be receiving its first funding for Vital Signs monitoring. The scoping meeting was timed so the Network could use the information gained during the meeting in the Vital Signs selection process.

This report summarizes the group's discussions and provides recommendations for studies to support resource management decisions, inventory and monitoring projects, and research needed to fill data gaps.

Government Performance and Results Act (GPRA) Goal Ib4
This meeting satisfies the requirements of the GPRA Goal Ib4, which is a knowledge-based goal that states, "Geological processes in 53 parks [20% of 265 parks] are inventoried and human influences that affect those processes are identified." The goal was designed to improve park managers' capabilities to make informed, science-based decisions with regards to geologic resources. It is the intention of the goal to be the first step in a process that will eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features, or cause critical imbalance in the ecosystem.

Because GPRA Goal Ib4 inventories only a sampling of parks, information gathered at the four parks may be used to represent other parks with similar resources or human influences on those resources, especially when findings are evaluated for Servicewide implications.

Geoindicator background information
An international Working Group of the International Union of Geological Sciences developed geoindicators as an approach for identifying rapid changes in the natural environment. The National Park Service uses geoindicators during scoping meetings as a tool to fulfill GPRA Goal Ib4. Geoindicators are measurable, quantifiable tools for assessing rapid changes in earth system processes. Geoindicators evaluate 27 earth system processes and phenomena (Appendix A) that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Appendix B). Geoindicators guide the discussion and field observations during scoping meetings (Appendix C). The geoindicators scoping process for the National Park Service was developed to help

determine the studies necessary to answer management questions about what is happening to the environment, why it is happening, and whether it is significant.

Aspects of ecosystem health and stability are evaluated during the geoindicators scoping process. The geologic resources of a park—soils, caves, streams, springs, beaches, volcanoes, etc.—provide the physical foundation required to sustain the biological system. Geological processes create topographic highs and lows; affect water and soil chemistries; influence soil fertility and water-holding capacities, hillside stability, and the flow regimes of surface water and groundwater. These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution and structure of ecosystems, and the resistance and resilience of ecosystems to human impacts (Appendix D).

Park Selection

These parks were selected to represent the Northern Colorado Plateau Network (NPCN) of parks. The parks will be the foci of research and development for protocols associated with vital-signs monitoring at NCPN parks and monuments. Geologic resources and processes found in these four parks are generally representative of those found throughout the rest of the NCPN, and considerable geologic research has been conducted in them previously.

Summary of Results and Recommendations

During the scoping meeting, geoindicators appropriate to Arches National Park, Canyonlands National Park, Capitol Reef National Park, and Natural Bridges National Monument were addressed. Of the 27 geoindicators (Appendix A), 21 were recognized as on-going processes to varying degrees in the four parks. An additional four geologic issues that are not part of the original geoindicators were also discussed (i.e., fire occurrence, atmospheric deposition, paleontological resources, and climate), as was an issue called "ecosystem response to geomorphic processes." The issues surrounding each geoindicator were identified, and participants rated the geoindicator with respect to the importance to the ecosystem, human impacts, and significance for resource managers (Geoindicators table). A compilation of the notes taken during the scoping session (Appendix G) and field trip (Appendix H) are included in the appendices. These notes may highlight additional information regarding geoindicators that may be useful to resource managers.

During the geoindicators scoping meeting, participants identified studies to support resource management decisions, inventory and monitoring projects, and research to fill data gaps at all four parks. The recommendations that follow are not listed in any order of priority, but are intended to help guide park managers when making decisions regarding natural resource management needs. The recommendations that are listed are by no means inclusive of all possible geological research and monitoring. A table that lists all the recommendations made during the meeting can be found in Appendix I.

Geoindicator table for Arches, Canyonlands, Capitol Reef national parks and Natural Bridges National Monument

Geoindicators	**Importance to park ecosystem**				***Human Impact**				****Significance to natural resource managers**			
	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE
ARID AND SEMIARID												
Soil crusts and pavements	5	5	5	5	5	5	5	5	5	5	5	5
Dune formation and reactivation	3	3	1	3	1	2	1	3	1	2	1	4
Dust storm magnitude, duration and frequency	1	1	1	1	5 1	5 2	5 1	5 3	3	3	3	3
Wind erosion (and deposition)	5	5	5	5	5 1	5 2	5 1	5 3				
SURFACE WATER												
Stream channel morphology	5	5	5	5	5	5	5	5	5	5	5	5
Stream sediment storage and load	5	5	5	5	5	5	5	5	5	5	5	5
Streamflow	5	5	5	5	5	5	5	5	5	5	5	5
Surface water quality	5	5	5	5	5	5	5	5	5	5	5	5
Wetlands extent, structure, hydrology	5	5	5	5	5	5	5	5	5	5	5	5
GROUNDWATER												
Groundwater quality	5	5	5	5	U	4	U	4	4	4	4	3
Groundwater level (and discharge)	5	5	5	5	5	5	5	5	5	5	5	5
SOILS												
Soil quality	5	5	5	5	1 5	1 5	1 5	1 5	5	5	5	5
Soil and sediment erosion (and deposition by water)	4	4	4	5	3 5	1 5	1 5	3 5	4	4	4	5
Sediment sequence and composition	1	1	1	1	4	4	4	5	3	3	3	3
HAZARDS												
Landslides, rockfalls, debris flows	3	2	2	3	1	1	1	1	1	1	1	2
Seismicity	2	1	1	1	3	3	0	0	1	1	1	1
Surface displacement (salt dissolution)	3	2	1	2	0	0	0	0	2	1	1	1
Fire occurrence	2	2	1	1	5	5	5	5	1	1	1	1
OTHER												
Atmospheric deposition (N, SO_4)	1	1	1	1	3	3	3	3	1	1	1	1
Paleontological resources	1	1	1	1	1	3	3	3	1	3	3	3
Climate	5	5	5	5	1	1	1	1	5	5	5	5

Geoindicators	Importance to park ecosystem				*Human Impact				**Significance to natural resource managers			
	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE	CANY	ARCH	NABR	CARE
OTHER												
Ecosystem structure and function characteristics as integrated indicators of geophysical (i) environments, (ii) processes, and (iii) changes/disturbances.	5	5	5	5	5#	5#	5#	5#	5	5	5	5
0 - Not Applicable (N/A) 1 - LOW or <u>no substantial</u> influence on, or utility for 3 - MODERATELY influenced by, or has some utility for 5 - HIGHLY influenced by, or with important utility for U - Unknown; may require study to determine applicability	*Includes current and potential impacts. If 2 rows, top = impacts of out-of-park activities on within-park condition; bottom = impacts of within-park activities. **Synthesis of first two columns and other miscellaneous factors #process specificity											

Significant geoindicators
The following is a summary of the results for the 11 geoindicators that rated the highest in all three categories, as well as the recommendations for these geoindicators that were proposed during the meeting. A summary of the scoping session discussion and the field trip are included in Appendix G and H, respectively. These notes highlight additional information regarding geoindicators that may be useful to resource managers.

<u>Desert surface crusts (biological and physiochemical) and pavements</u>
Biological soil crusts composed of varying proportions of cyanobacteria, lichens, and mosses are important and widespread components of terrestrial ecosystems in all four parks, and greatly benefit soil quality and ecosystem function. They increase water infiltration in some soil types, stabilize soils, fix atmospheric nitrogen for vascular plants, provide carbon to the interspaces between vegetation, secrete metals that stimulate plant growth, capture nutrient-carrying dust, and increase soil temperatures by decreasing surface albedo. They affect vegetation structure directly due to effects on soil stability, seedbed characteristics, and safe-site availability, and indirectly through effects on soil temperature and on water and nutrient availability. Decreases in the abundance of biological soil crusts relative to physicochemical crusts (which can protect soils from wind erosion but not water erosion, and do not perform other ecological functions of biological crusts) can indicate increased susceptibility of soils to erosion and decreased functioning of other ecosystem processes associated with biological crusts.

Human impacts
Off-trail use by visitors, past trampling by cattle in Arches and Canyonlands national parks, and present trampling by cattle in Capitol Reef National Park have damaged soil crusts significantly in some areas. Soil nutrient cycles, as well as most other benefits of biological soil crusts, have been compromised in these areas.

Recommendations
Inventory condition and distribution of biological soil crusts.

Investigate connection between ecosystem function and biological crusts.
Map crust communities in relation to environmental factors.
Study crust recovery rates and susceptibility to change.
Study crust population dynamics and conditions.

Wind erosion and deposition

In addition to water, wind is a major force that can redistribute soil and soil resources (e.g., litter, organic matter, and nutrients) within and among ecosystems. Erosion and deposition by wind is important in all four parks and can be accelerated by human activities. Accelerated losses of soil and soil resources by erosion can indicate degradation of arid-land ecosystems because ecosystem health is dependent on the retention of these resources.

Human impacts

Trampling and vegetation alteration by livestock as well as human recreational activities such as hiking, biking, and driving off of established trails and roads can destabilize soils and increase soil susceptibility to wind erosion. Some localized heavy visitation areas within parks have seen crust death by burial from windblown sands when nearby crusts have been trampled, such as in the Windows area of Arches National Park

In addition, wind erosion and sediment transport may be strongly impacted by land-use practices outside the parks. Eolian sand from disturbed surfaces may saltate onto undisturbed ground, burying and killing vegetation and/or biological soil crusts, or breaking biological soil crusts to expose more soil to erosion. Because park management practices limit or prohibit off-road travel, human impacts within the parks primarily are associated with off-trail hiking in high-use areas. Where livestock grazing or trailing is still permitted (e.g., CARE), accelerated soil erosion can be more extensive.

Recommendations

Monitor movement of soil materials (see Recommendations table).
Investigate ecosystem consequences of movement (**Contact:** Jason Neff, 303-236-1306, jneff@usgs.gov**)**
Investigate natural range of variability of soil movement in relation to landscape configuration and characteristics. (**Contact:** Jason Neff, 303-236-1306, jneff@usgs.gov**)**

Stream channel morphology

The morphology of stream channels impacts the vegetative structure of the riparian corridor, affects the height of the water table, and affects the energy of water flow downstream (which affects erosion rate and water quality). Stream channels are vital components of aquatic and riparian ecosystems in these arid-land parks.

Human Impacts

Potential for human impact on stream channel morphology is great. These impacts include building parking lots and structures in or near channels, building structures in floodplains (e.g., culverts and bridges), livestock grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion.

Recommendations
Conduct hydrologic condition assessment to identify actual and potential “problem reaches” for prioritized monitoring.
Once “problem reaches” are identified, monitor with repeat aerial photographs.
Once “problem reaches” are identified, monitor with repeated cross-sections. Some data are available for Capitol Reef, Canyonlands, and Arches national parks. (See Recommendations table).

Stream sediment erosion, storage and load
Participants added “erosion” in order to clarify and encompass the total geomorphic picture regarding stream function. The original title is “stream sediment storage and load.” This geoindicator is important to the ecosystem because sediment loads and distribution affect aquatic and riparian ecosystems, and because sediment loading can result in changes to channel morphology and overbank flooding frequency.

Human impacts
The potential for human impact to stream sediment erosion, storage, and load is great. These impacts include building parking lots and structures in or near channels, building structures (e.g., culverts and bridges) in floodplains, grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion.

Recommendations
Conduct research concerning ungaged stream sediment storage and load. There are no data available except on the main stem of the Colorado River at Cisco, Utah, and the Green River at Green River, Utah.
Measure sediment load on streams of high interest for comparative assessment. Data will provide information for making management decision.

Streamflow
Streamflow is critical to the maintenance of aquatic and riparian ecosystems. Streamflow impacts the structure of the riparian corridor, affects the height of the water table, and affects water quality and erosion rates.

Human impacts
The potential for human impact on streamflow is great. These impacts include building parking lots and structures in or near channels, building structures (e.g., culverts and bridges) in floodplains, grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion.

Recommendations
Identify important hydrologic systems that would benefit from knowledge of streamflow. Existing gauging stations are located on the Green River (Green River, Utah), San Rafael River (near Green River, Utah.), Fremont River (at Cainville, Utah, and above Park at Pine Creek.), and on the Muddy River. Many other gauging stations exist (see USGS Web site). Additional data exists for streams in Capitol Reef National Park and for Courthouse Wash in Arches National Park. Other relevant data exists with the local U.S. Geological Survey, Water Resources Division.
Research effects of land use and climatic variation on streamflow.
Investigate paleoflood hydrology.

<u>Surface water quality</u>
For detailed understanding of the issues and what has been done with regards to water quality data for the four NPS units, see the June, 2002, trip report prepared by Don Weeks in Appendix J. There are a number of park-specific water resource reports cited in the report that are particularly pertinent.

Human impacts
The potential for negative affects on groundwater quality by human activity is significant. The following are specific issues that could impact groundwater quality:
Herbicide use to decrease tamarisk populations.
Trespass cattle at springs.
Abandoned oil and gas wells within and close to NPS boundaries may result in saline waters infiltrating into groundwater supplies.
Abandoned uranium mines and mills.
Impacts from recreational uses (these have not been quantified).

Human impacts in Canyonlands National Park
Old landfill in Needles District (approx. 1 mile from Visitor Center, and 3,000 ft from a domestic well) had unregulated dumping from 1966-1987.
Texas Gulf Potash Mine located downriver from Moab on the Colorado River.

Human impacts in Arches National Park
Contamination from the Atlas tailings pile.
Water rights associated with springs and wells near the park boundary, particularly those associated with Courthouse Wash, Lost Spring Canyon, and Sevenmile Canyon.

Human impacts in Natural Bridges National Park
Abandoned copper and uranium mines.

Human impacts in Capitol Reef National Park
Natural radioactivity may occur in portions of the Fremont River where it flows through uranium-ore bearing strata of the Chinle Formation.
Pesticide use by park managers to maintain the historic orchards.

Recommendation
Obtain information about existing baseline water quality data for all four parks (**Contact**: Don Weeks, 303-987-6640, don_weeks@nps.gov). Also see Don Weeks June, 2002, trip report in Appendix J.

<u>Wetlands extent, structure, and hydrology</u>
Wetlands are important ecosystems because they stabilize streambanks, act as filters to improve water quality, attenuate floodwaters, enhance biodiversity (important habitat for amphibians, reptiles, birds, and Threatened and Endangered Species), are highly productive in terms of biomass and nutrient productivity, and are valuable water sources for wildlife and recreationists.

Human impacts
The potential for human impacts on wetlands is great. These impacts include building parking lots and structures in or near channels, building structures (e.g., culverts and bridges) in floodplains, grazing in uplands and stream channels, roads and trails up streambeds, introduction of exotic species, and impacts from flow regulation and diversion. In addition, agricultural activities and past extirpation of beaver have affected wetlands.

Recommendations
Inventory location, character, and conditions of wetlands in all four parks.
Inventory distribution of exotic species in wetlands.
Monitor groundwater levels and surface elevations.
Investigate age-structure and populations of woody riparian plants in relation to land use history.
Investigate links between amphibian health attributes and wetland health.

Groundwater quality
The quality of groundwater in the parks has a high impact on hanging gardens, which are located in all four parks. Hanging gardens are unique features that contain rare plant species, and provide important wildlife habitat. Groundwater quality is also an issue for safety and health regarding water quality for human use. To further understand what the issues are and what has been done with regards to water quality data for the four NPS units, see Appendix J.

Human impacts
The potential for negative affects on groundwater by human activity is significant. All four parks identified specific issues that could impact groundwater quality.

Human impacts in Arches National Park
Grazing near Courthouse Wash and Sevenmile Canyon springs may have affected groundwater quality.
The effects of mining and oil and gas drilling are unknown.

Human impacts in Canyonlands National Park
Old landfill in the Needles District had unregulated dumping from 1966-1987.
Oil well sites had improper dewatering.
The effects of mining and oil and gas drilling are unknown.

Human impacts in Capitol Reef National Park
The effects of mining and oil and gas drilling are unknown.
There is standing water in mines within the park.
There is a National Park Service septic field near the Fremont River.

Human impacts in Natural Bridges National Monument
The impacts of copper and uranium mining and oil and gas drilling are unknown.

Recommendations
Locate and inventory all seeps, springs, and hanging gardens.
Prioritize seeps, springs, and hanging gardens for assessment of water quality.

Acquire plugging records of oil and gas wells potentially connected to park groundwater systems **(Contact:** Bob Higgins, 303-969-2018, bob_higgins@nps.gov **)**.
Use geochemical indicators to investigate groundwater flow areas, flow directions and recharge area, and groundwater age.
Identify and study potential sources for groundwater quality impacts at all four parks, including those listed above (**Contact**: Don Weeks, 303-987-6640, don_weeks@nps.gov). (See Appendix J.)

Groundwater level and discharge

Outside the river corridors in Canyonlands and Capitol Reef national parks, groundwater supplies much of the water available for wildlife, and supplies 100% of the park's water supply for human use.

Human impacts
Groundwater is a limited resource, and the potential for human impact is great. Current human impacts are poorly understood.

Recommendations
Inventory and research are needed concerning groundwater quality, level, and discharge.
Install transducers and dataloggers in wells.
Develop methods for measuring water discharge from seeps and hanging gardens **(Contact:** Bob Webb, 520-670-6671, rhwebb@usgs.gov**)**.
Investigate additional methods to characterize groundwater recharge areas and flow directions **(Contacts:** Charlie Schelz, 435-719-2135, charlie_schelz@nps.gov and Rod Parnell, 928-523-3329, roderic.parnell@nau.edu).

Soil quality
Soil quality affects moisture retention, nutrient cycling, soil-food webs, and aggregate structure. Soil also provides biogeochemical and hydrologic support for terrestrial productivity, especially vegetation growth. Soil quality degradation results in loss of certain ecosystem functions, such as nutrient cycling.

Human impacts
Due to past and present grazing in the parks, nutrient cycles have not recovered.

Recommendations
Assess existing soil-crust conditions in relation to potential (as an indicator of soil quality) and in relation to soil maps.
Repeatedly measure soil quality in disturbed sites to gain understanding of recovery rates in relation to environmental factors, such as soil texture, topographic position, and climate.
Quantify natural range of variability in quality in relation to environmental factors.
Develop predictive model for potential biological soil crust distribution/structure/function in relation to environmental factors, such as soil texture, soil chemistry, topographic position, and climate.
Investigate susceptibility to change (e.g., climate and UV).
Study resistance and resilience of soil to human disturbances.

Soil and sediment erosion and deposition by water
During the discussion of this geoindicator, participants chose to focus on water transport and deposition, therefore the words, “and deposition by water” were added to this geoindicator. Transport and/or loss of soil may result in degradation of soil quality (see Soil quality geoindicator).

Human impacts
In general, past grazing practices has caused soil erosion in all four parks. There is still occasional trespass of cattle in Arches and Canyonlands national parks and Natural Brides National Monument.

Human impacts in Capitol Reef National Park
Grazing is still permitted.
Topographic gradients are high; therefore, erosion along roads (both currently-used roads and those used for past practices, such as mining) and cow trails is potentially great.

Recommendations
Investigate/develop methods for monitoring erosion and deposition quantitatively and affordably, and determine the best locations to monitor **(Contact:** Bob Webb, 520-670-6671, rhwebb@usgs.gov).
Assess conditions of soil erosion (e.g., qualitative hydrologic function).

Ecosystem response to geomorphic processes
Because many types of ecosystems are highly dependent on the geomorphic process and substrate, ecosystem response to geomorphic processes is highly important to park ecosystems. Disturbance to ecosystems is inevitable, whether the disturbance is human or natural caused. Management actions that attempt to mitigate disturbances, and particularly restoration of disturbed areas, may be influenced by the types of geomorphic processes involved and/or the nature of geomorphic substrates. Knowledge of predicted ecosystem responses to disturbances may affect the decision of whether to actively rehabilitate a disturbed site or whether to allow it to recover naturally. If active rehabilitation or restoration is chosen, this knowledge should determine what types of species are suitable for the underlying geomorphic conditions. Land-use practices, as well as climatic fluctuations may have an impact on ecosystem response. The perceived significance by managers depends upon need in the wake of an important disturbance that may instigate a management response.
(**Contacts**: Bob Webb, 520-670-6671, rhwebb@usgs.gov; and Rod Parnell, 928-523-3329, roderic.parnell@nau.edu)

Recommendations
Acquire high quality surficial geology, soil, and vegetation maps for all four parks. Current availability of soil and geologic mapping varies among the parks.
Determine what to monitor, where, and with what attributes/indicators.
Research spatial and temporal relations among ecosystem structure and function, geologic substrates, and geomorphic processes.
4. Assess change-detection methods.

List of Participants

National Park Service
Tom Clark, Capitol Reef National Park, Torrey, Utah
Craig Hauke, Southeast Utah Group, Moab Utah
Bob Higgins, Geologic Resources Division, Lakewood, Colorado
Alison Koch, Fossil Butte National Monument, Kemmerer, Wyoming
Greg McDonald, Geologic Resources Division, Lakewood, Colorado
Mark Miller, Northern Colorado Plateau Network, Moab, Utah
Mary Moran, Southeast Utah Group, Moab, Utah
Andy Pearce, Aztec Ruins National Monument, Aztec, New Mexico
Bruce Rodgers, Southeast Utah Group, Moab, Utah
Vince Santucci, Fossil Butte National Monument, Kemmerer, Wyoming
Charlie Schelz, Southeast Utah Group, Moab, Utah
Dave Sharrow, Zion National Park, Kanab, Utah
Gery Wakefield, Southeast Utah Group, Moab Utah
Don Weeks, Water Resources Division, Lakewood, Colorado

U.S. Geological Survey
Jayne Belnap, Moab, Utah
Jason Neff, Denver, Colorado
Marith Reheis, Denver, Colorado
Rich Reynolds, Denver, Colorado
Bob Webb, Tucson, Arizona

Other
Charles Bishop, Utah Geological Survey, Salt Lake City, Utah
Larry Coats, Northern Arizona University, Flagstaff, Arizona
Hugh Hurlow, Utah Geological Survey, Salt Lake City, Utah
Lynn Jackson, Bureau of Land Management, Moab, Utah
Katie KellerLynn, NPS Contractor, Estes Park, Colorado
Dan Martin, Brigham Young University, Provo, Utah
Tom Morris, Brigham Young University, Provo, Utah
Rod Parnell, Northern Arizona University, Flagstaff, Arizona
Doug Powell, Bureau of Land Management, Kanab, Utah
Mike Young, Westfield State College, Westfield, Massachusetts

Geoindicator Appendix I: Recommendations Table

Geoindicators	Baseline Data (existence and adequacy)	I & M (I&M needs)	Research
Ecosystem structure-and-function characteristics as integrated indicators of geophysical (i) environments, (ii) processes, and (iii) changes/disturbances.	- process-level data are almost non-existent - of available, most information is for NEED-CANY - current availability and adequacy of soil and geologic mapping varies among parks - 10-m DEMs are available for all four parks - 1:12K aerial photos & DOQQs to be acquired within next year - veg maps scheduled to be completed within 4 years	- surficial geology maps - soil maps - vegetation maps - research will determine what to monitor, where, and with what attributes / indicators	- spatial and temporal relations among ecosystem structure / function, geologic substrates (e.g., chemistry, texture, landform attributes), and geomorphic processes - assess change-detection methods - determine which attributes are best suited as indicators
ARID AND SEMIARID			
1. Desert surface crusts (bio & physicochem) and pavements (same for all 4 parks)	- ARCH has best existing data; needs at CANY, NABR and CARE are greater	- inventory current distribution, composition and condition relative to potential	- investigate connection between ecosystem function and biocrusts - develop predictive map of potential composition / structure of crust communities in relation to environmental factors - investigate recovery rates in relation to disturbance and environmental factors - determine susceptibility to change, e.g. changing climate, UV - study population dynamics and condition in disturbed vs. undisturbed

Geoindicators	Baseline Data (existence and adequacy)	I & M (I&M needs)	Research
ARID AND SEMIARID			
2. Dune formation and reactivation	- existing data almost nonexistent - surficial geology map for small portion of NEED-CANY	- inventory required (geologic maps omit sand sheets) – i.e., map spatial distribution of sand sheets and dune features - following inventory, assess and categorize dunes / sand sheets with respect to (re)activation susceptibility - potentially monitor by repeated aerial photography (possibly with 5-year repeat interval)	- P/PE mapping to support susceptibility assessment (which will require automated climate stations) - research concerning potential (re)activation thresholds - investigate ecosystem consequences of dune reactivation
3. Dust storm magnitude, duration and frequency (bad-visibility days)	- currently being monitored at ISKY-CANY, ARCH, CARE - regional data are adequate, but local are not	- if there is a local issue....then local I&M data are required -otherwise, nothing additional is needed	- nothing locally
4. Wind erosion (ecosystem inputs / outputs of soil resources excluding water)	-some data are available from NEED-CANY for erosion & deposition - new dust traps recently installed at ARCH & ISKY-CANY (new inputs) - nothing elsewhere	- monitor movement of soil materials	- investigate better measurement / monitoring methods - investigate ecosystem consequences of movement - investigate natural range of variability in relation to landscape configuration and characteristics (Neff)
SURFACE WATER			
5. Stream channel morphology	- some cross-section data are available for Salt Creek (NEED-CANY), Courthouse Wash (ARCH), and Lost Spring (ARCH) - gauging stations in Courthouse Wash - miscellaneous cross-section data from Fremont R. & some other CARE systems - 1:12K aerial photos & DOQQs to be acquired within next year	- conduct hydrologic condition assessments to identify actual / potential "problem reaches" for prioritizing monitoring (e.g., PFC) - monitor with repeat aerial photographs - monitor with repeated cross sections	

Geoindicators	Baseline Data (existence and adequacy)	I & M (I&M needs)	Research
SURFACE WATER			
6. Stream sediment erosion, storage and load	- no data available except for main stem of Colorado River (at Cisco) and Green River (at Green River, UT)		- conduct research concerning ungaged stream sediment storage and load - potential gaging of high-interest streams for comparative assessment of sediment measures in relation to management
7. Streamflow	- existing gages on Green R. (Green R. UT) San Rafael R. (near Green R.) Fremont R. (Cainville & above Park at Pine Crk.), Muddy River (uncertain location)...... –many other existing gages....see USGS website; - some additional flow data for CARE streams, Courthouse Wash ARCH - miscellaneous relevant data –see local USGS WRD -regionalized flood-frequency studies for UT and arid western-region states	- identify important hydrologic systems that would benefit from knowledge of streamflow - criteria: critical riparian systems, TES taxa, potential up-stream land-use effects, water-right issues, recreational use, management interest / controversy	- effects of land-use and climatic variation on stream flow - investigate paleoflood hydrology
8. Surface water quality	- see information compiled by CSU for NCPN		- investigate effects of sunscreen on water quality in springs
9. Extent, structure, and hydrology of riparian / wetland systems	- see 5,6,7,8 above - current macroinvertebrate monitoring in SEUG - current riparian bird and vegetation monitoring in SEUG - limited amphibian inventory at CANY - see veg mapping comments elsewhere	- inventory location and character of wetlands (first step is to look at existing NWI maps—but these would only capture larger systems) - potentially conduct inventory of riparian & wetland condition (e.g., PFC) - inventory spatial distribution of exotics - monitor groundwater levels and surface elevations	- investigate age-structure of woody riparian plants in relation to land-use - investigate potential linkages between amphibian parameters and wetland health

Geoindicators	Baseline Data (existence and adequacy)	I & M (I&M needs)	Research
SURFACE WATER			
10. Lake levels and salinity			
GROUNDWATER			
11. Groundwater quality	-uncertainty exists concerning groundwater effects of old mines (all parks) and the buried landfill at NEED-CANY - baseline water quality data are available for some springs in SEUG, but not for seeps/hanging gardens	- conduct inventory (determine location) of all springs / seeps / hanging gardens (need in GIS) - assess current water quality in a prioritized subset of these, accounting for seasonal variability - (prioritized on basis of potential human use, potential human impact, ecological parameters) - inventory location and plugging record of oil/gas wells potentially connected to park groundwater systems	- use geochemical indicators to investigate groundwater flow areas, flow directions and recharge area, and groundwater age
12. Groundwater chemistry in the unsaturated zone			
13. Groundwater level and discharge	-	- install transducers and dataloggers in wells (transducers measure pressure of the water in the well) -inventory and research (concerning groundwater quality and level/discharge) must be completed prior to monitoring	- investigate / develop methods for measuring water discharge from seeps and hanging gardens (Webb) - investigate additional methods to characterize groundwater recharge area and flow directions
14. Subsurface temperature regime			
15. Karst activity (salt)			

Geoindicators	Baseline Data (existence and adequacy)	I & M (I&M needs)	Research
SOILS			
16. Soil quality	- some data available for NEED, ARCH; very limited elsewhere	- assess existing bio crust condition in relation to potential (as indicator of soil quality) and in relation to soil map units - repeatedly measure soil quality in previously disturbed sites to gage recovery rates in relation to environmental factors	- quantify natural range of variability in relation to environmental factors - develop predictive model for potential biological soil crust distribution/structure/function in relation to environmental factors (bio crust as indicator of soil quality) - investigate susceptibility to change, e.g. changing climate, UV - resistance and resilience to disturbance factors
17. Soil and sediment erosion & deposition by water (upland environments)	- current availability and adequacy of soil and geologic mapping varies among parks - 10-m DEMs are available for all four parks - 1:12K aerial photos & DOQQs to be acquired within next year - veg maps scheduled to be completed within 4 years - some data are available for fluvial erosion of sandy soils at NEED	- conduct condition assessments (e.g., qualitative hydrologic function—rangeland health) - stratify assessments in relation to landscape units and potential impacts - stratify monitoring in relation to landscape units and results of condition assessments	- investigate / develop methods for monitoring this quantitatively and affordably .... and determine where best to monitor (Webb)
18. Sediment sequence and composition	- some data are available from auger holes, soil pits, & micro sediment sequences from soil crusts at NEED & ARCH	- none	- identify sites, acquire cores, analyze in relation to local and regional land-use histories (potential link with Colorado Plateau CESU); objectives are to quantify natural range of variability in sediment quantity and composition and effects of land use

Geoindicators	Baseline Data (existence and adequacy)	I & M (I&M needs)	Research
HAZARDS			
19. Slope failure (landslides)	- no data exist for rockfalls - data exist for debris flows in CANY along river	- use repeat ground and aerial photography to monitor debris flows in Cataract Canyon (for assessment of effects on navigation) - land slides should be reported if regularly occurring (e.g., to assess potential for damming creeks/canyons)	- continue studying spatiotemporal distribution of slope failures in relation to bedrock structure & lithology
20. Seismicity	- the data exist and are quite adequate	- consider asking USGS to install seismic monitoring devices in parks (not necessary, but possibly interesting)	
21. Surface displacement (including salt dissolution features)	- graben offsets have been monitored at CANY - previous seismic data have been collected for CANY, ARCH	- continue to monitor graben offsets	
OTHER			
23. Atmospheric deposition (N, SO4)	- defer to air-quality monitoring		
24. Paleontological resources	- paleo survey has been conducted at ARCH; very limited info avail for other parks - limited surveys for potential Quaternary resources at all parks - geologic maps exist for all parks - preliminary literature searches for all parks have been conducted	- conduct comprehensive inventories - monitoring will be required, but needs will be contingent on inventory results	- research needs will follow from inventory results

Geoindicators	**Baseline Data (existence and adequacy)**	**I & M (I&M needs)**	**Research**
OTHER			
25. Climate	- CANY has 5 automated stations and 30-yr daily record - WRCC website provides long-term data for parks and surrounding stations - ARCH (~50 yr) & NABR have daily data - CARE has ~35 years of daily data - CARE has 3 years of data from automated station in the parking lot	- more automated stations needed - canvas for locations of additional / unofficial recording stations	- develop spatial model of rainfall to determine what locations would benefit from a station (to support monitoring) - develop spatial distribution of PET and climatic water balance as a function of landscape / substrate features (to support monitoring)

Appendix L. NCPN Science Panel Members and Program-Review Comments

Compiled by:

Mark Miller, USGS-BRD

18 September 2003

Contents

Introduction

This appendix presents information pertaining to NCPN efforts to engage the scientific community (i.e., scientists other than NPS staff and USGS protocol-development partners) as participants in the development of the monitoring program. Included are several background documents used by the NCPN to solicit interest from the scientific community and to describe envisioned roles of external scientific experts. In November 2002, six scientists agreed to work with the NCPN as an Independent Science Review Panel (ISRP, or "science panel"). Since that time, these individuals have provided critical review comments concerning various aspects of the program and have participated in activities associated with vital-sign evaluation and selection. All review comments submitted by science-panel members through September 2003 are presented in this Appendix. Most recently, the science panel provided official peer-review comments on an earlier draft of this Phase II report. These review comments and NCPN responses also are included in this Appendix.

CALL FOR TECHNICAL EXPERTISE AND POTENTIAL COLLABORATORS

NATIONAL PARK SERVICE
NORTHERN COLORADO PLATEAU NETWORK
INVENTORY & MONITORING PROGRAM

19 AUGUST 2002

Introduction

The Northern Colorado Plateau Network Inventory and Monitoring Program (NCPN I&M Program) of the National Park Service (NPS) coordinates natural-resource inventories and long-term ecological monitoring in 16 NPS units on and around the Colorado Plateau. NPS goals for long-term ecological monitoring are as follows:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

As part of this new program, the NCPN is in the process of developing a plan for long-term ecological monitoring in network parks. NCPN staff have the need for external technical experts to provide scientific guidance and critical reviews periodically during the development of the monitoring plan. This call is intended to identify (1) available expertise in disciplines integral to long-term ecological monitoring, and (2) potential partners and collaborators in the development and/or review of the monitoring plan. This is not a call for proposals regarding specific projects.

Potential Scope of Needs

Outside collaborators with appropriate technical expertise may be invited to participate in numerous tasks associated with monitoring-plan development. Examples include:

1. Review of the monitoring program's overall conceptual framework and goals.

2. Review of conceptual models developed to describe (1) linkages among key components and processes of terrestrial, riparian, and aquatic ecosystems of the Colorado Plateau, and (2) pathways by which anthropogenic stressors affect changes in ecosystem structure, function, and sustainability.

3. Review of conceptual models developed to describe the population ecology of sensitive plant and animal populations (including Federally listed threatened or endangered species) and how anthropogenic stressors may impact the viability of these populations.

4. Formulation of specific ecological monitoring questions on the basis of management issues identified by NPS staff.

5. Participation in an electronic Delphi poll concerning conceptual ecosystem models, ecological indicators, and approaches to long-term monitoring of Colorado Plateau ecosystems and sensitive populations.

6. Review and synthesis of results from the Delphi poll.

7. Identification, prioritization, and selection of ecological indicators for long-term monitoring of ecosystem condition and/or viability of sensitive populations.

8. Identification of research needs associated with the identification, characterization, and quantification of ecological indicators that may provide managers with advance warning that critical ecological thresholds are being approached.

9. Consultation regarding spatially explicit study designs for long-term ecological monitoring, including sample-size determination, power analyses, computation of minimum detectable change, and analytical methods for long-term data sets.

10. Review and development of sampling protocols for selected ecological indicators.

11. Review of proposals and/or manuscripts associated with long-term monitoring projects.

Desired Fields of Expertise (specific expertise in monitoring applications is desirable)

- Arid-land ecology
- Forest ecology
- Riparian ecology
- Aquatic ecology, including integrated application of physical, chemical, and biological indicators in water-quality monitoring
- Fluvial geomorphology of arid-land streams and rivers
- Soil ecology
- Rangeland ecology
- Fire ecology
- Population ecology and monitoring of rare and/or sensitive plants
- Population ecology and monitoring of rare and/or sensitive vertebrates including avifauna, amphibians, mammals, and fish
- Ecology, early-detection, and treatment of invasive exotic species (plants and/or animals)
- Ecological risk assessment
- Ecological modeling
- Remote sensing

- Landscape ecology
- Spatially explicit monitoring design
- Statistical and other quantitative methods applicable to long-term ecological monitoring, specifically:
    - Parametric and nonparametric trend analyses
    - Uncertainty analyses
    - Time series analyses
    - Spatial statistics

Notice of Availability and Interest

Persons who possess technical expertise applicable to long-term ecological monitoring and are interested in participating as partners and collaborators in the development and/or review of the NCPN monitoring plan should contact Dr. Angela Evenden, NCPN Coordinator, by October 1, 2002.

NATIONAL PARK SERVICE
NORTHERN COLORADO PLATEAU NETWORK
INVENTORY & MONITORING PROGRAM

THREE TIERS OF SCIENTIFIC REVIEW AND GUIDANCE

NOVEMBER 2002

The Northern Colorado Plateau Inventory and Monitoring Network (NCPN) of the National Park Service (NPS) has the need for technical experts to provide scientific guidance and critical reviews periodically during the development of their plan for long-term ecological monitoring in 16 NPS units on or around the Colorado Plateau. Three levels or tiers of scientific input are envisioned, as follows:

Tier 1 – Independent Scientific Review Panel (ISRP, or "science panel")

Focus: Overall conceptual framework, process for selection of vital signs, research recommendations, adaptive-management considerations, general scientific oversight.

Membership criteria: (1) Recognized expertise in scientific field(s) pertinent to long-term ecological monitoring, (2) independence (i.e., no personal or professional stake in outcomes of monitoring-design process), (3) broad ecological perspective (i.e., demonstrated ability to span scales and levels of ecological organization), and (4) for the group as a whole, a mix of institutional affiliations.

Number of members: 5-6 individuals.

Organization: Standing panel.

Means and frequency of communication: One or two face-to-face meetings per year (initially, two during FY 2003); periodic conference calls and electronic correspondence.

Tier 2 – Ad hoc subject-matter experts

Focus: Detailed guidance regarding specific taxa, ecosystems, methods, protocols, sampling designs, etc. A subset of ad hoc experts may be asked to participate in the post-Delphi scoping workshop to be held in spring 2003.

Membership criteria: Recognized expertise in resource-management issues and/or scientific disciplines pertinent to long-term ecological monitoring.

Number of members: 30-50 – including researchers specifically involved in protocol-development work (e.g., USGS prototype partners) and members of NCPN technical committee. May include Tier 1 experts.

Organization: None (with exception of USGS prototype partners and NCPN technical committee).

Tier 3 – The larger community of resource-management professionals and scientific subject-matter experts

Focus: Participation in Delphi process (electronic scoping poll). In general, members of the Tier 3 group will not participate in the post-Delphi scoping workshop unless they are members of higher tier groups.

Membership criteria: Recognized expertise in resource-management issues and/or scientific disciplines pertinent to long-term ecological monitoring.

Number of members: From 50 to a few hundred. May include Tier 1 and Tier 2 experts.

Organization: None.

NATIONAL PARK SERVICE
NORTHERN COLORADO PLATEAU NETWORK
INVENTORY & MONITORING PROGRAM

INDEPENDENT SCIENTIFIC REVIEW PANEL

16 DECEMBER 2002

Introduction

The Northern Colorado Plateau Network Inventory and Monitoring Program (NCPN I&M Program) of the National Park Service (NPS) coordinates natural-resource inventories and long-term ecological monitoring in 16 NPS units on and around the Colorado Plateau. NPS goals for long-term ecological monitoring are as follows:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

As part of this new program, the NCPN is in the process of developing a plan for long-term ecological monitoring in network parks. NCPN staff have the on-going need for external technical experts to provide independent scientific review and guidance during the development of the monitoring plan. Much of this review and guidance will be provided by an Independent Scientific Review Panel (ISRP, or “science panel”) consisting of members of the scientific community who (1) are recognized experts in subject areas pertinent to long-term ecological monitoring, (2) have no personal or professional stake in the outcome of decisions associated with development of the monitoring plan, and (3) can perform review and guidance tasks free of forceful persuasion by others associated with development of the monitoring plan. Scientific review and guidance will be provided by panel members on an individual basis, and it is not the purpose of the panel to submit consensus recommendations or reports. This document outlines goals of independent scientific review, the anticipated scope of science-panel responsibilities, time commitments of science-panel members during the 2002-2003 period, and compensation that will be provided by NPS to science-panel members.

Goals of Independent Scientific Review

Meffe and colleagues (1998:268) identified seven goals of independent scientific review (ISR) in natural resource management. ISR is intended to help ensure that:

1. The best available scientific knowledge is brought into the decision- or policy-making process;
2. The influences of bias and special interests are minimized in environmentally relevant decisions or policy making;
3. Science is separated clearly from nonscientific issues;
4. Decisions or policies are achieved in an open and transparent manner;
5. All relevant information is considered and evaluated;
6. All conclusions drawn are consistent with the available scientific information, and assumptions are made explicit; and
7. The risks associated with different interpretations of data or alternative management decisions are articulated.

Scope of Science Panel Responsibilities

The scope of the science panel responsibilities will be to provide scientific review and guidance concerning:

1. The monitoring program's overall conceptual framework and goals;
2. Specific conceptual models developed to describe (1) linkages among key components and processes of terrestrial, riparian, and aquatic ecosystems of the Colorado Plateau, and (2) pathways by which anthropogenic stressors affect changes in ecosystem structure, function, and sustainability.
3. The process and criteria for identifying, prioritizing, and selecting "vital signs" – ecological indicators for long-term monitoring of ecosystem condition and/or viability of sensitive populations;
4. The formulation of questions posed to experts in electronic Delphi polls and syntheses of electronic poll results;
5. Research needs associated with the identification, characterization, and quantification of ecological indicators that may provide managers with advance warning that critical ecological thresholds are being approached;
6. The development of rigorous sampling protocols associated with vital-signs monitoring;
7. The cultivation of a productive relationship with the broader scientific research community;
8. The development of requests for proposals to meet scientific research needs, and reviews of solicited research proposals;
9. The adaptive-management process involving periodic reevaluation of program goals and priorities, monitoring methods, monitoring results, and management implications.

Anticipated Time Commitment for Science Panel Members

When	Task	Estimated time commitment
Dec. 2002	Review NCPN Phase I report (1 October 2002 document) in preparation for face-to-face meeting on 17 December in Denver.	1 day (or less)
Dec. 2002	Participate in 1-day face-to-face meeting with NPS to discuss role of science panel and comment on Phase I report.	1-3 days, depending on travel requirements.
Dec. 2002 – Jan. 2003	Prepare individually written comments on selected portions of Phase I report, recommendations regarding the vital-signs selection process, and recommendations regarding short- and long-term research needs (see review guidelines from M. Miller dated 11/25/02).	1 day
Week of 7 April 2003	Participate in vital-signs scoping workshop, Moab.	4-5 days (including travel)
May 2003	Prepare individually written comments on vital-signs workshop, indicator-selection process and selected indicators.	1day (or less)
Late summer 2003	Review and comment on draft Phase II report.	1 day (or less)
Yearly after September 2003	One annual meeting, periodic document reviews, occasional ad hoc calls.	4-8 days

Compensation for Science Panel Members

The NCPN will reimburse science panel members for travel costs associated with face-to-face meetings and workshops. For panel members who are not federal government employees, the NCPN will provide a $500 honorarium as compensation for meeting participation.

Literature Cited

Meffe, G. K., P. D. Boersma, D. D. Murphy, B. R. Noon, H. R. Pulliam, M. E. Soulé, and D. M. Waller. 1998. Independent scientific review in natural resource management. *Conservation Biology*: 268-270.

NCPN Independent Scientific Review Panel

13 November 2002

Dr. Jill Baron
U.S. Geological Survey – Biological Resources Discipline
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80523
Phone: 970.491.1968
Fax: 970.491.1965
Email: jill@nrel.colostate.edu
http://www.nrel.colostate.edu/projects/lvws/pages/homepage.htm

Dr. Barry Noon
Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, CO 80523-1474
Phone: 970.491.7905
Fax: 970.491.5091
Email: brnoon@cnr.colostate.edu

Dr. Robert (Buck) Sanford Jr.
Department of Biological Sciences
University of Denver
Denver, CO 80208
Phone: 303.871.3534
Fax: 303.871.3471
Email: rsanford@du.edu
http://www.du.edu/biology/sanford.html

Dr. John (Jack) Schmidt
Department of Aquatic, Watershed, and Earth Resources
Utah State University
Logan, UT 84322-5150
Phone: 435.797.1791
Fax: 435.797.4048
Email: jschmidt@cnr.usu.edu

Dr. Tim Seastedt
Professor of EPO Biology
INSTAAR, CB 450
University of Colorado
Boulder, CO 80309-0450
Phone: 303.492.3302
Fax: 303.492.6388
Email: Timothy.Seastedt@colorado.edu, tims@culter.colorado.edu
http://stripe.colorado.edu/~tims/

Dr. Joe Truett
Senior Scientist, Turner Endangered Species Fund
P.O. Box 211 (1/4 mi Catwalk Road)
Glenwood, NM 88039
Phone: 505.539.2188
Fax: 505.539.2187
Email: jtruett@gilanet.com

Science Panel Comments on NCPN Phase I Report

Date: 18 December 2002

To: NCPN Science Panel Members

From: Mark Miller

Subj: Review guidelines, NCPN Phase I Report

As indicated previously, we would like each of you to independently review our Phase I report and provide written comments and recommendations. Although we certainly would welcome comments and recommendations concerning any and all portions of the document, in particular we're looking for your input regarding Chapters III and IV. I provide some further guidance on these chapters below.

"Disciplinary assignments"

Given the breadth of your expertise, I anticipate that each of you will be able to provide insightful review comments and recommendations concerning many different aspects of the Phase I report and the developing monitoring plan. However, to ensure that certain bases are covered, I ask that each of you pay particular attention to the following areas:

- Jack Schmidt – riparian systems, geomorphology, hydrology
- Jill Baron – aquatic systems, water quality
- Joe Truett – wildlife, landscape-level perspective, workshop & process management
- Barry Noon – wildlife, landscape-level perspective, monitoring science
- Buck Sanford – terrestrial systems, soils
- Tim Seastedt – terrestrial systems, invasives, soils

Background

Though we're not asking you to review Chapter II *per se*, it provides important background and context. Here's an abbreviated guide to the chapter so you don't have to wade through the Table of Contents:

- Background on NPS Inventory & Monitoring, pp. 1 – 3
- "Network" (16 units) vs. "Prototype Cluster" (5 units nested within the 16), pp. 3 – 8 (also, see map on p. 5)
- Approach to Monitoring Planning, pp. 9 - 21
- Goals, pp. 25 - 27
- Overview of Parks and Natural Resources, pp. 27 – 53 (descriptions of individual parks are in Appendix L)

- Management and Scientific Issues, pp. 53 - 64
- Overview of Existing Monitoring, pp. 69 – 74

Chapter III

The intent of this chapter is (1) to describe a general conceptual framework on which to establish a scientifically defensible and rigorous monitoring program; and (2) to describe our hypotheses and assumptions regarding key ecosystem components/processes and the pathways by which anthropogenic stressors affect them. Together, these are intended to guide the identification and selection of vital signs. The chapter is incomplete, but the direction is evident. I prepared the general framework and materials for arid-semiarid ecosystems – mostly borrowing from others, as you'll see. Lynn Cudlip, a contractor working with us on water-quality issues, prepared the material focusing on riparian and aquatic systems – emphasizing water quality. I intend to expand and revise the riparian and aquatic models so that they are consistent with the general model and parallel to the approach used for arid-semiarid systems, to the degree possible. I also will prepare a section on montane systems that is parallel to the arid-semiarid approach.

In addition to the chapter being incomplete, I recognize some important conceptual weaknesses in the existing structure of the chapter. These are scale issues, landscape-level considerations, and wildlife (in general). Ultimately, we envision the program consisting of landscape-level monitoring, ecosystem-level monitoring, selected "stressor" monitoring (e.g., exotics, visitors), and monitoring of selected sensitive or "focal" wildlife species. I have yet to pull all of these components together in a useful framework.

Some questions to consider during your review:

- *Is the overall conceptual framework logical, scientifically sound, and useful for purposes of identifying, prioritizing, and selecting indicators?*

- *Does the framework make sense in relation to the stated goals of the program?*

- *Are the tabular and state-and-transition models presented for arid-semiarid systems logical, scientifically sound, and useful for purposes of identifying, prioritizing, and selecting indicators?*

- *Does the approach used for arid-semiarid systems (e.g., Tables 25 & 26) seem generally transferable to aquatic, riparian, and montane systems?*

- *Do you have suggestions for improved consideration of scale and landscape-level processes?*

- *In general, how does the direction of this chapter look in relation to where you think it needs to go for purposes of vital-signs selection and monitoring design?*

- *What are the strengths and weaknesses of material presented in Chapter III?*

Chapter IV

As indicated by the information presented on p. 108, our process for arriving at vital signs remains to be defined clearly. In addition to the science panel, we will solicit input from a larger group of scientists concerning conceptual models and potential indicators. An internet-based Delphi process will be the primary method for soliciting this input (to be conducted during January and February 2003). Additional input will be solicited on an ad hoc basis. A vital-signs workshop (which we hope you will attend) will be held in April 2003. The desired outcome of this workshop will be a prioritized list of vital signs for the network. Vital signs will encompass the three monitoring themes (ecosystem structure and function, invasive species, and sensitive species) as well as other priority resource concerns of parks. *We would really appreciate your thoughtful input regarding how to shape this process*.

A reality check concerning funding: So far, we have taken a fairly comprehensive approach to developing the monitoring plan. But the reality is that the expected level of annual funding -- just less than $ 1 million / yr for all 16 parks, including both network and prototype programs – will support monitoring that is far less than comprehensive. Despite the meager funding, the intent is to develop a solid framework that we can build on with funding from other sources / programs. The immediate need is for a good process that facilitates agreement on priorities.

What are your views concerning the process and criteria used for identifying, prioritizing, and selecting vital signs that are meaningful and that we can afford to monitor?

Research Needs

In addition, we're interested in your views concerning short-term and long-term research needs associated with the development of the monitoring plan. The U.S. Geological Survey (USGS) is a partner in the development of the monitoring program. For a limited number of years, they have additional funding (i.e., separate from NPS program funding) to develop monitoring protocols associated with particular "themes" identified for emphasis in the "prototype" parks. [In Volume I, see p. 7 for introduction of the Prototype Program and Appendix V for discussion of prototype themes.] Jayne Belnap with USGS here in Moab has been the lead on the protocol development, and Appendix V briefly describes her research focus to date. We are interested in your views regarding the current focus of this work in relation to the overall need for protocol-development research – i.e., how we might expand or redirect this effort, if at all.

Dr. Jill Baron's Comments on NCPN Phase I Report, January 2003:

Review of Chapter III of the
Northern Colorado Plateau Plan for Natural Resources Monitoring
Phase 1 Report.

You are to be applauded for the thoroughness with which this report is put together. There is a wealth of information contained here. Part of the success in a long-term monitoring program is knowing the current baseline, and Volume 2 of the Report represents a good start. I have a number of general comments, many of which we spoke about at out meeting in Denver, and these will be followed by specific comments on Chapter III.

1. Although the NCPN is partly an artificial construct of some, but not all, similar parks, it mostly represents a true region - the Colorado Plateau. The state of these parks reflects in large part the state of the entire region, and the monitoring program and how the results actually get interpreted will be a lot more successful in the long run if you adopt a regional perspective from the very beginning. This has a number of ramifications for how you go about gathering information, possibly in how the sampling program is designed, and certainly in how it is interpreted.

A. Information about the state of park resources must not be confined to that collected within park boundaries. The large lists within Volume 2 represent a good start, but someone (or more than one) with subject matter expertise should now collect and synthesize what is known about the state of the resources (forests, grasslands, soils, aquatic systems, wildlife, etc). We, and the park managers that will use the report, will get a much better feel for the State of the Region if literature is gathered from the whole scientific body that is out there (for example Web of Science) and from other agencies and groups that have looked at natural resources of the Plateau. These could include, among others, BLM, FWS, USGS, USDA Forest Service, Department of Defense, state agencies, as well as private conservation groups, like The Nature Conservancy.

B. Compilation of this information should then be developed into a history of the Colorado Plateau environment, concluding with the current State of the Environment. This well-documented chapter, summarizing natural resources, should have two parts: one that describes the regional condition, and a second part that does the same park by park. I recommend this become one of the first chapters of the Phase 1 Report, and be written so that it tells the story of resource use, ending with a compelling message for why inventory and monitoring of resources is necessary.

C. The reasons for taking this extra effort at the beginning are 1) inventory and monitoring will be much easier to adopt by managers if they can see the big picture. While the I&M program is nationally mandated now, in 10 -20 years time it may be forgotten. A compelling document that describes the resources, how they've changed, and why it is critical to monitor repeatedly for additional change may go along way toward continuing the interest in monitoring; and 2) it sets a foundation for the theory that follows.

D. Selection of vital signs (what to monitor and why) should also be placed in a regional, and even larger context. It will be important, of course, to monitor the appropriate indicators of condition and change for the NCPN parks, but these indicators should be selected with full knowledge of what is being monitored by other land management agencies in the region, and what national indicators are being chosen. This is important because understanding of regional change wll be just as important as understanding park-specific change. It will also be important if regional-scale management actions are necessary. If the attributes selected for NPCN parks differ in type or frequency from regional and national attributes, we should think carefully about whether there are appropriate conversions that will allow blended data sets, or if adjustments or additional measurements are warranted.

2. The goal of this project is not the collection of inventory and monitoring data; it's the <u>interpretation</u> of them. We want to KNOW and TRACK the changes in natural resources. Interpretations of the data will most certainly be used to justify management decisions, and they may be used in courts of law. It will be important to set up the protocols so that the most appropriate information is collected in the most robust way, and you have already thought quite a bit about this. You have some criteria listed on p. 97 of the report for how to select indicators, there are more in Kurtz et al. 2001, and we'll be working through that with the Delphi process. But the I&M program doesn't end with the collection, quality checking, and safe storage of information. It needs to be interpreted by knowledgeable scientists and naturalists on a yearly basis (preferably people in your regional network office). It also needs to be synthesized scientifically and published in the peer-reviewed literature regularly. With due respect for the theory behind detecting change, it's very hard to state with confidence that change has occurred in real environments and real time, which is why it is crucial to interpret them regularly, and PUBLISH these interpretations. That's another reason for freely allowing access to data to anyone who wants it - multiple eyes and perspectives may lead to detection of change using different methodologies than NPS will use. Outsiders bring fresh perspectives to the interpretation when they analyze these data for their own hypotheses, questions, and school projects. Access to data also promotes good will.

3. I wasn't sure who the audience for Chapter III is supposed to be. Parts of it were useful (to me) for thinking about how to design a monitoring program. Other parts were not. Although there are examples specific to NPCN systems in it, it was rather abstract. The conceptual model based on Jenny's soil-forming factors is an excellent foundation and justification for what to study. That makes perfect sense, although I suggest you combine Figures 12 and 13 into one big one with parts a., b., c., and d. Incidentally, what is "airborne recreation" in Figure 13b (Kite-flying)?

The reason for incorporating the section on stability, thresholds, and resilience was less clear. How will this theory be used in the I&M program? As stated above, it is very difficult to predict state changes before they occur, and sometimes difficult to interpret one that has already occurred without knowing *a priori* what the natural variability of a system is. This section might be easier to interpret with specific examples of how or where one would apply this theory. Some of the text even moves beyond I&M and interpretation of the results, to management, such as Figures 18 and 20 and their discussion. How does this help set a framework for monitoring?

4. I may be in agreement with Jack Schmidt that the large rivers of the NCPN parks are really external to the park resources NPS can really do something about. Unless NPS is already taking responsibility for monitoring environmental quality of the Colorado, Green, Virgin, and the Fremont, I don't think they should be added. But that leaves an exciting collection of intermittent streams, potholes and tinajas, hanging valleys, and springs that need to be monitored with far more rigor than simply gathering 305b-required EPA water quality standards. There are unique biological communities here, and the importance of these water bodies for desert animals is disproportionately important. Monitoring should be tuned, therefore, to detect changes that will affect the communities that rely on these scarce water bodies. The actual list of indicators and frequencies still needs to be determined, but spatial extent of the freshwaters, shoreline and riparian condition, water quality, flow, and status of native and non-native species will be important for surface waters. Seeps and springs will need monitoring, as you state, of upstream groundwater aquifers. Tables 25 is generally applicable to aquatic systems, but probably far more detailed than will be really useful in selection of indicators of change. Table 26 captures most of the appropriate disturbances, although effects to groundwaters from pollution and land use change far removed from seeps and springs is not included.

<u>Dr. Barry Noon's Comments on NCPN Phase I Report, January 2003:</u>

January 15, 2003

To: Mark Miller, NPS
From: Barry R. Noon, CSU
RE: Review comments on Chapter III

Comments on Chapter III

1) *Is the overall conceptual framework logical, scientifically sound, and useful for purposes of identifying, prioritizing, and selecting indicators?*

In general, I found chapter III to be a thorough review of the literature relevant to conceptual model development. I am aware of a few additional references that may be relevant and I will list them below.

There are numerous challenges in developing useful conceptual models. In my opinion, the primary challenge when developing a model of a managed ecosystem is to provide guidance to indicator (vital sign) selection. Since most useful prospective monitoring programs have a stressor orientation, the conceptual models should illustrate the "locations" of anticipated stressor action. By location I mean the attributes (i.e., processes, structural and compositional elements, and species) of the ecosystem expected to be affected by stressor action. These attributes become candidate indicator variables.

To accomplish the above, requires an exhaustive list of stressors, the ecosystem elements affected by the stressors, and a characterization of the stressors. To characterize the stressors many questions should be addressed. For example, is the stressor of human or natural origin? Does the stressor primarily originate external or internal to park boundaries? If the stressor acts, are its effects generally reversible or irreversible? Is the stressor chronic or acute in its action? Does the stressor act at the local, watershed, or park scale? And so on. I believe that these (and other) questions need to be addressed in order to begin the process of indicator selection.

Finally, the conceptual model(s) should reflect the different scales of action of stressors and the ecosystem elements expected to affected at these scales. For example, consider timber harvest as a stressor of forest ecosystems. One scale of stressor action is at the stand level and elements expected to change would be canopy cover, the diameter distribution of trees, and the amount and size of dead and down woody material. Considering multiple harvest units at the watershed scale would lead to changes in the age-distribution of stands, measures of fragmentation, and sediment loads in streams. At the landscape scale, I might expect changes in the abundance, distribution, and connectivity of late seral patches of forest.

Admittedly, including all the components of conceptual models discussed above is a tall order to capture in a single model. Thus, it may be best to develop a family of models each reflecting a specific spatial scale, or each reflecting a specific stressor. The bottom line, I think, is that the model both guides indicator selection and explains to the public why you are measuring what you are measuring, and what it tells you about the integrity of the ecosystem.

In reviewing the conceptual models in chapter III (figures 22-25), I found that they included many of the components discussed above. I think they are a very good start but need to be made more specific to specific ecosystems are parts of ecosystems. Where I think the models were deficient was in explicitly providing insights into the scale of stressor action. Also, you may want to provide more discussion in the text on the characteristics of the stressors (as discussed above) and some estimate of the likelihood of them impacting the park. Finally, due to pragmatic reasons (minimal funds), I think you may need to reduce your stressor list to reflect those most likely to occur and most likely to lead to irreversible effects.

2) *Does the framework make sense in relation to the stated goals of the program?*

By stated goals I am assuming you are referring to the broad goal to "protect the environment and preserve our nation's natural and cultural resources." I am further assuming that the environment is inclusive of the totality of physical and biological resources present at the creation of the park, and this includes objectives to maintain the original distribution and abundance of these resources.

The proposed framework makes sense in that achievement of the goal requires monitoring of the status and trends of the environment. If the status and trend of the resources the NPS is charged to protect suggests a lack of compliance, then appropriate changes in management practices may be required.

The reality, of course, is that it is impossible to determine the status and trend of all resources. As a consequence, some surrogate-based approach is required. This becomes an additional dimension for indicator selection. Not only are indicators selected on their ability to reflect stressor action, additional indicators are need to allow inference to the state of the ecosystem to which they belong. That is, these are indicators that are both information-rich and integrative.

I suggest that a revision of Chapter III include a discussion of the different types of indicators (vital signs) that are important aspects of a comprehensive monitoring program. At a minimum these would include early-warning, stressor-based, information rich, functional dominants, at-risk species indicators.

3) *Are the tabular and state transition models presented for arid-semiarid systems logical, scientifically sound, and useful for purposes of identifying, prioritizing, and selecting indicators?*

I did not find these to be very useful (for example, I did not understand what was being communicated in the bar graphs). This may be because they were not described sufficiently or that I need to do more background reading.

4) *Does the approach used for arid-semiarid systems seem generally transferable to aquatic, riparian, and montane systems?*

The process for developing conceptual models should be general and easily transferred across different ecosystems. For example, I have recently come across a set of papers on restoration of the Kissimmee River ecosystem in Florida and was struck by its similarity to what was developed for the Pacific Northwest. (These papers are found in the September 1995 issue of Restoration Ecology). I was unaware of these papers when I was directing the science team developing the monitoring program for the NW Forest Plan so the similarities in approach occurred independently.

Another point of interest that occurred to me when reading the Kissimmee River papers were the similarities in the goals of ecosystem restoration and ecosystem monitoring. To restore an ecosystem requires an image of the desired future state of the system. This can be based on historic benchmark conditions or simply restoring processes and composition to some semblance of past conditions. In a similar fashion, monitoring requires a specification of desired states in order to assess if management goals are being achieved. Both involve the concept of a probability distribution of states (some more likely than others) and thus acknowledge a range of natural variation.

5) *Do you have suggestions for improved consideration of scale and landscape-level processes?*

When most ecosystem elements vary continuously the task of identifying discrete scales of analysis and measurement becomes difficult. One way to begin to address this question is to first ask if there are obvious discontinuities in time or space in the elements or processes of the managed system. From my work in forested ecosystems I think there are some logical temporal and spatial scales for birds of prey. For example, working with spotted owls we have detected that meaningful scales include the nest tree, the forest stand (~ patch) in which the nest tree resides, the home range (~ 2500-6000 acres), and the local population as a collection of home ranges (> 60,000 acres). Meaningful temporal scales for owls are the breeding season (~ 2 months), the over-winter period (~ 4-6 months), the annual cycle, age to first reproduction (2 yrs), and life span (~ 10 yrs). If the monitoring program is centered on a small set of species, one way to determine appropriate spatial scales for sampling is to estimate them via allometric relationships relating body size to space-use. In this case, we would ask what stressors operate at a given scale and are likely to affect species which scale their environment at that scale or smaller.

For ecological systems, appropriate spatial and temporal scales are less obvious but may be a function of the scale and return interval of disturbance events. For example, disturbance events such as the death of an individual tree, loss of a forest stand due to wind-throw, replacement of a forest mosaic due to catastrophic fire, and changes in vegetation communities due to climate change have somewhat characteristic temporal and spatial scales. The fact that there is an expected distribution of disturbance events when plotted in a time by space ordination helps to define a ‘natural’ range of variability.

Scale considerations have recently been addressed in river ecosystems (Fausch et al. 2002). The authors of this paper recognize that there are some apparent discontinuities in river systems when defined in terms of spatial life history events relevant to fish. Fausch et al. partition the 'riverscape' into pools (0.1 km), reaches (1 km), segments (10 km), and watersheds (100 km). As for the spotted owl, here the spatial partitioning of the landscape occurs relative to a focal species or species group.

There exist other more theoretical approaches to estimating the 'appropriate' scale for environmental measurements. These use the tools of geostatistics to estimate the area over which specific species or processes demonstrated spatial autocorrelation. I think these methods have merit when the assessment is highly focused on a single species or ecological process. However, I think they are less useful for more extensive ecosystem-based monitoring programs.

In summary, my recommendation for determining appropriate scales of measurement for ecosystem-level processes is to focus on the extent and return interval of the key disturbance events (both natural and human-induced). This suggests that the best indicators can be derived from remotely sensed data and methods of change detection. For example, natural disturbance events may result in an expected distribution of seral stages or patch size distribution that can be compared to that estimated from remotely sensed data gathered from the actual landscape. For focal species assessments, I suggest using estimates of how they scale their environment by using allometric relationships. In terms of a monitoring program, this means identifying indicators that reflect stressors (or threats) operating at these scales. These can be direct measures of the species populations, or surrogate measures based on habitat attributes.

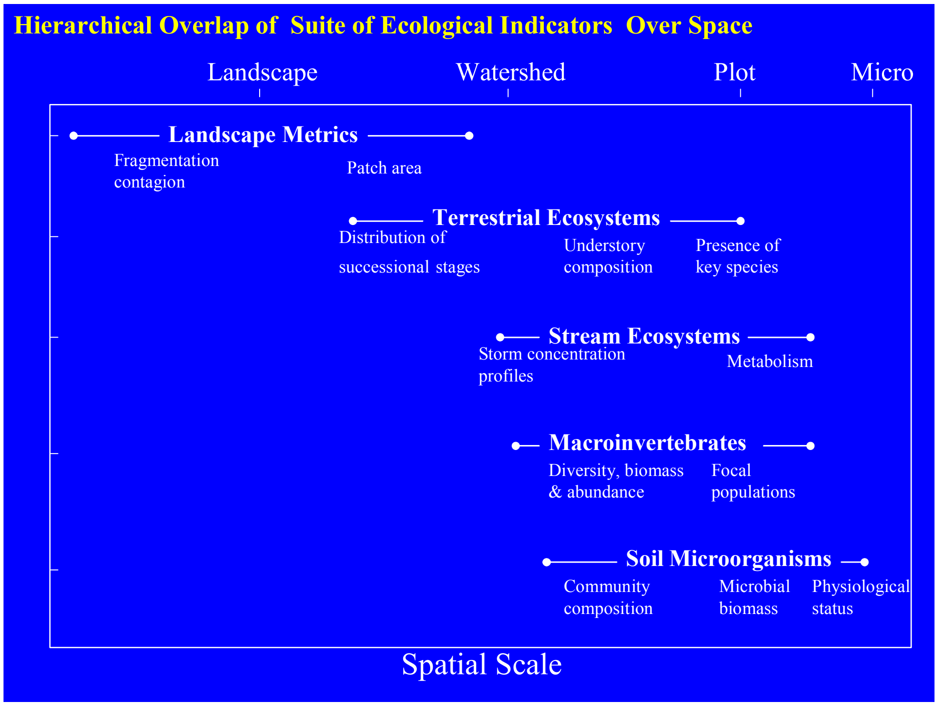
6) *What are the strengths and weaknesses of material presented in chapter III?*

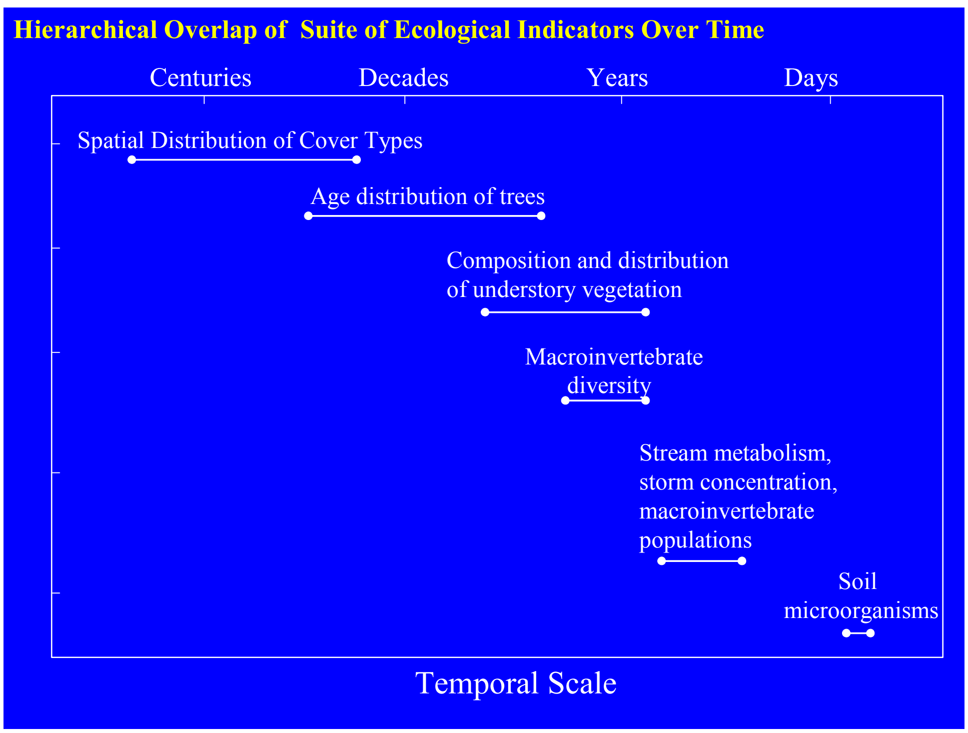
It is my opinion that you have made great progress towards developing a comprehensive monitoring program. The next logical step is to refine your conceptual models with an eye towards stressor identification and indicator selection. I believe a comprehensive monitoring program should include a set of indicators that represent ecosystem processes processes, landscape structures, and species.

References

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: Bridging the gap between research and conservation of stream fishes. Bioscience 52:483-498.

Gentile, J.H., and others. 2001. Ecological conceptual models: a framework and case study on ecosystem management for south Florida sustainability. The Science of the Total Environment 274:231-253.


Hierarchical Overlap of Suite of Ecological Indicators Over Space
Landscape
Watershed
Plot
Micro
Landscape Metrics
Fragmentation
contagion
Patch area
Terrestrial Ecosystems
Distribution of
successional stages
Understory
composition
Presence of
key species
Stream Ecosystems
Storm concentration
profiles
Metabolism
Macroinvertebrates
Diversity, biomass
& abundance
Focal
populations
Soil Microorganisms
Community
composition
Microbial
biomass
Physiological
status
Spatial Scale


Hierarchical Overlap of Suite of Ecological Indicators Over Time
Centuries
Decades
Years
Days
Spatial Distribution of Cover Types
Age distribution of trees
Composition and distribution
of understory vegetation
Macroinvertebrate
diversity
Stream metabolism,
storm concentration,
macroinvertebrate
populations
Soil
microorganisms
Temporal Scale

<u>Dr. Jack Schmidt's Comments on NCPN Phase I Report, January 2003:</u>

John (Jack) C. Schmidt
Department of Aquatic, Watershed, and Earth Resources
Utah State University
10 February 2003

Annotated Comments on

Northern Colorado Plateau Plan for Natural Resources Monitoring Phase I Report

<u>General comment on abbreviations used in the Phase I report.</u>

I strongly suggest that you dispense with the use of the 4 letter designations of the various park units, since these abbreviations accomplish a goal of excluding the general public from readily understanding tables and charts using these terms. The abbreviations do not immediately arise from the unit names and are not intuitive. They only accomplish the goal of excluding general understanding.

<u>General comment on the regional designation itself:</u>

There are obvious problems in the geographic boundaries of this region that ought not to be dismissed at this point, despite the fact that much administrative activity is already underway. Discussion at our Denver meeting revealed that there was general recognition of these problems, yet no one seemed willing to take on the issue, due to prior administrative decisions. Acquiescence to such political realities is not the job of scientific advisors.

Given the central status of water resources in the maintenance of the ecosystems of these park units, strong consideration ought to be given to aligning the NCPN units with the boundaries of generally accepted water related phenomena pursued by other agencies. Central ideas that might be considered are the concept of watershed boundaries and the concept of the Upper Colorado River Basin, as defined by the Colorado River Compact. From both perspectives, Glen Canyon National Recreation Area ought to be included in the NCPN. Glen Canyon Dam and Lees Ferry, Arizona, mark the hydrologic and political boundaries between the Upper and Lower Colorado River basins and integrated ecosystem management of the region would establish the boundary of the region at this point. Since the water quality of Lake Powell reservoir and its tributaries are determined by the NCPN region, there is no scientific justification for establishing the boundary of the NCPN and SCPN at the boundary of Canyonlands National Park.

Similarly, the inclusion of Zion N.P. in the NCPN makes little sense for the same reasons. One might also reconsider the distinction between NCPN and SCPN in general. The assemblage of park units that extend down the Green and Colorado Rivers from Dinosaur and Black Canyon of the Gunnison to Lake Mead N.R.A. have a strong and compelling unified principal that would force attention and focus on the status of the main rivers of the region.

Obviously, one encounters the issue of inclusion of the other small park units of the SCPN, such as Hovenweep and Walnut Canyon. I would argue that the Colorado Plateau units whose central focus is archaeology and that are located on ephemeral washes and upland settings constitute a different suite of park units and could be considered differently. My concern is that the role of the main rivers in the park ecosystems that include the Colorado River and its major tributaries is a dominant theme that ought to be integrated in development of ecosystem monitoring plans.

On the other hand, the inclusion of Golden Spike and Timpanogos Cave in the NCPN makes little sense, and the sites are better considered part of the Great Basin ecosystem. The inclusion of Fossil Butte in the NCPN makes more sense because the monument is located at the edge of the Green River basin and its natural history association is linked to that at Dinosaur NM.

Specific comments:

p. 1, 2 A conceptual jump is made from the description of the NPS mission to "conserve … natural and cultural resources" to the stated need for "park based biological information." One might argue that all natural systems are *ecological* and that *ecological* and *biological* refer to the same natural system attributes. However, I think that this logic may be flawed and you might consider that the natural resources of the park units include geologic, hydrologic, geomorphic, and air resources that most people would not necessarily describe as biological.

p. 8 It is notable that there is a strong emphasis on water quality, but I would suggest that there is a logical inconsistency in this discussion. It is true that aquatic, riparian, and wetland ecosystems play an essential role in the NCPN. It is also true that water quality is a key element in water resources. It is less clear, however, that water quality is the limiting attribute in the water-related ecosystems of the NCPN. Instead, I suggest that water quanitity issues are the most important limitation and deserve greater emphasis in the region and in this report.

p. 16 It is notable that no where in Table 3 is the category "water flux" mentioned, yet this issue, more than "water body location" and "water quality" are essential to the region's ecosystems.

p. 19 I appreciate the candor of your report on the subcontracting issues.

p. 56, 57 These tables indicate inconsistencies in the perception of Green River-related problems by the staffs of Dinosaur and Canyonlands, particularly concerning native fish, TES fish, water quantity, and dam operations. I would expect that a regional report would reconcile these differences before publication of such tables.

p. 64 No mention is made of issues, and decisions, and federal reserved water rights which have profound effects on park ecosystems. Such a decision has already been made in Zion, has been proposed at Black Canyon, been lost in part of Dinosaur and considered elsewhere.

General Comments on Chapter III

This chapter reviews general ecological theory in an effort to provide guidance in the development of an ecosystem monitoring plan. General models and concepts are reviewed and the details concerning arid and semiarid ecosystems are discussed in specifics. More details are to be forthcoming regarding other ecosystem types.

Since I am not an ecologist, review of the details of ecological theory are better left to others, and I will focus on general observations regarding the physical sciences.

First, I am struck by the general direction of this discussion and its sole focus on ecological theory. There is a wide literature concerning hydrological and geomorphic systems that could, and should, be brought to bear on the topic of foundations of ecosystem monitoring. I am struck by figures such as 15, 16, and 17 which seem to have been copied from seminal papers in geomorphic theory published within the past 20 years. The review of ecological theory is very helpful to me, but the discussion is one sided, as if no other groups of landscape scientists ever thought of the same things.

Although ecosystems may be a term intended to mean all abiotic and biotic systems, the fundamental role of abiotic systems in the NCPN is so strong that there ought to be distinct and stand-alone discussion about the concepts of how the geologic/hydrologic/geomorphic/soils systems interact and evolve in upland settings and how the geologic/ hydrologic/ground water/soils systems interact in riverine settings.

I respectfully suggest that there are some general topics that would better set the stage for establishment of an ecological monitoring program. One topic that this document would do well to review is our understanding of the environmental history of the NCPN region. It is imperative that the NPS describe its understanding of how the regional landscape has evolved to its present condition. Such a discussion would lead to NPS discussion of the phenomena of arroyo cut-and-fill in its park units and the role of this climate and land use driven process in determining the resultant hydrologic flow field and associated ecological responses. What is the general understanding of what has happened in the past century? The sensitivity of these systems to changes in climate? How would NPS distinguish between land use-driven arroyo cutting and climate-driven arroyo cutting? What models allow distinguishing between headwater and downstream changes? What magnitude of change in the geomorphic characteristics of ephemeral streams allows one to distinguish between the effects of small dams and diversions and effects associated with infiltration, climate, and nonnative riparian plants?

The narrow focus on water quality and the general avoidance on water quantity persists in this chapter. I think that this narrow focus is due to the fact that the document does not include a section called something like – "how the regional natural system functions." In such a description, one might acknowledge that the streams of the desert parts of the region carry a naturally high sediment load and may carry high dissolved loads. Thus, it is difficult to distinguish perturbations in such systems. One might describe the water quality assessment programs of CO, UT, and WY in an effort to provide background on how each state assesses perturbations in the NCPN.

However, the bigger concern is water quantity. Such a concern is made manifest by the existence of the NPS unit on Water Rights and the negotiations concerning Zion NP in-stream flows water. A major focus in this program ought to be on describing changes in water flow caused by dams and diversions, changes caused by land use and non-native plants, changes caused by climate change, and changes to sediment yield and sediment transport. In places like Dinosaur and Canyonlands, new alluvial deposits have been created by the altered stream flows of the Green River and the invasion of tamarisk, and such changes ought to be acknowledged and be a focus of monitoring.

Although the general models concerning springs, seeps, and hanging gardens are sound, they also are so general as to provide little guidance as to how one would construct a monitoring system. I think one ought to focus discussion on topics like: "since we could not feasibly ever measure ground-water flux near every spring in the region, are we better to measure the outflow of every spring in order to determine regional trends or should be study in detail a few places scattered around the region where we actually measure all the things shown on Figures 23 and 24."

In regards to rivers, the general model can be made more specific and simple: river channel form is determined by the flux of water (primarily the magnitude and duration of floods) and the flux of sediment (primarily the quantity and size of the imposed load). Thus, one can measure the attributes of channel form (cross-section characteristics, bed material, planform, and slope) or one can measure the driving variables (water and sediment). Or one could measure the watershed characteristics that determine the water and sediment flux. The further one removes oneself from the actual driving variables, the harder is the chore of making causal links. But the more one studies these processes in detail, and at a meaningful precision and accuracy, the more one is forced to only study a few sites and then assume general regional trends. I would like to see these issues discussed in the document.

Dr. Tim Seastedt's Comments on NCPN Phase I Report, January 2003:

NPS Northern Colorado Plateau Network Inventory and Monitoring Program, Phase I Report

Tim Seastedt, Jan. 10, 2003

Enclosed are my thoughts regarding the draft NCPN Inventory and Monitoring Program. I've used the seven guiding questions to frame the report. As you might expect, the review is biased towards terrestrial systems, invasives, and soils.

This draft effort is in excellent shape. I found the document to be well thought out and comprehensive. My comments therefore tend to tweak or pick at details rather than attempt any major overhauls. I appreciate the focus on adaptive ecosystem management using a strong conceptual model to understand the factors generating ecosystem structure and function. The document recognizes that specific management activities (or, in some cases, the lack of proactive management activities) can directly and indirectly influence structure and function. Further, the document identifies that the mechanism for evaluating management relative to goals is through a proactive monitoring and assessment program. This is, in my view, a state-of-the-art exercise.

The key to a successful program is to ensure that adequate data are collected, adequately documented, and analyzed in a timely manner. As one who has been involved in long-term monitoring and research, I've come to believe that the exact composition of the data set and exact experimental framework for obtaining those data are probably only as important as the mechanisms in place to document and use this information. The initial exercise to survey what data are available and document those data using standard formats was a very logical and appropriate activity.

I. Is the conceptual framework adequate?
One model seldom fits all, but the Jenny (1941, 1980) state factors model is viewed as very powerful and robust by ecologists attempting to understand ecosystems and ecosystem phenomena. The NCPN should impose its own "weighting" to this model.
Clearly, NPS sites in this network (excluding historical/anthro/paleo considerations) were selected because of 'topographic richness', and it's this topographic richness, in combination with a unique climate and unique biota (esp. the microbiotic crusts, which can play such a critical role in ecosystem integrity), tend to organize these ecosystems.
As I mentioned at the meeting, our high-elevations group, which includes both terrestrial and aquatic ecologists, has chosen to use a new conceptual model that tweaks Jenny's model with others, including the river continuum concept of Vannote et al. 1980. The value to us is the emphasis that transport processes have on the structure, functioning, and species changes with of our system. This would appear to be the case for many of the NCPN sites.

II. Does the framework make sense relative to the goals of the program?
In a word, yes. I was pleased that the report did not attempt to heavily exploit the concept of "restoring systems to match their "historical range of variability" (i.e., an extensive analysis of

fire and flood return intervals, insect outbreaks, etc.). There are simply too many new variables that limit the usefulness of this concept to current situations involving new climates, new atmospheric chemistry, new species, and regulated flow regimes. It's time we recognize that these systems are in fact outside their historical range of variability and manage them accordingly using principles provided by adaptive ecosystem management.

III. Are the tabular and state-and-transition models appropriate for identifying prioritizing, and selecting indicators?
I'm less impressed with the power of state transition models to assist in thinking about ecosystem change. While these models are useful, I've found that managers often begin to see them as deterministic rather than stochastic processes. I would probably downplay this material, or make sure that managers understand that huge uncertainties exist applying these general concepts to specific systems.

IV. Can semi-arid, terrestrial approaches be useful for aquatic, riparian and montane systems?
I think so. This is essentially a modified Jenny five-factor approach, with parent material and topography combined into a single interactive control. As mentioned above, the combination of a Jenny model with one that emphasizes transport processes, is how we've organized our high elevation 'montane' effort.

V. How can the scale and landscape issues be improved?
Indicators come with implicit or explicit scaling factors. A review of the NRC or the Heinz report on the selection of indicators appears to deal with these in a pragmatic way, one that is appropriate given financial limitations. Rather than try to be exhaustive or comprehensive, an explicit analysis of scale relationships for each of the selected indicators should be available and known. Selection of indicators should also have an explicit statement regarding scale limitations or scale applications for each unit.

VI. How are we doing in terms of vital-signs selection and monitoring design?
One exercise that seemed underutilized here was the approach taken by the Heinz Report, which demanded that indicators be selected to deal with a subset of particular ecosystem characteristics. This approach might be of value here, particularly as a preliminary exercise for the various sites of the NCPN. If park X had to select indicators to monitor fragmentation, nutrient status, chemical contaminants, physical conditions, etc., what would be selected? Obviously the NPS mission here is more focused than the Heinz program, and goals and mandates may preclude a more general approach. However, the thought of having some chemical monitoring (e.g., my favorite, nitrate...) within a biologically oriented program is appealing to me.

VII. Strengths and weaknesses of chpt III?
This lets me wander into areas not discussed above, or emphasize points I feel strongly about. As I mentioned, I approach this effort from what I think is a pragmatic perspective, one that's been tempered by 20 years of collecting data for specific projects, but then also using those data to assess environmental change (e.g., Hobbie et al. BioScience, Jan. 2003). From this I believe that historical data sets, particularly those that can be revisited (i.e., reinventoried), are gold mines. Even though these data may be incomplete or flawed, they provide the fastest way for making at least preliminary statements about change. Building a new system that can exploit

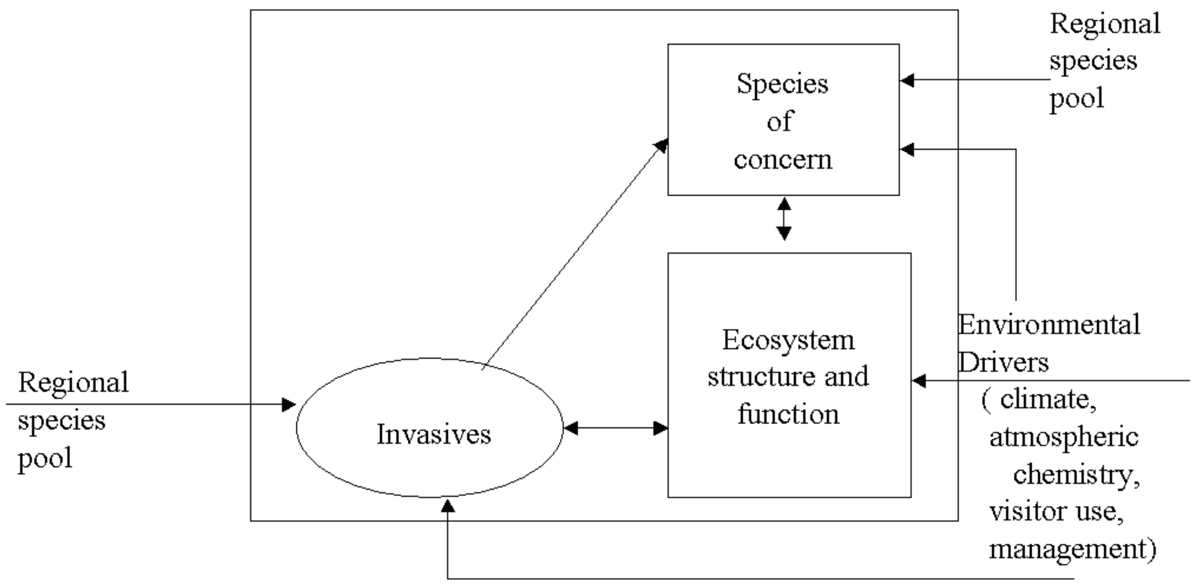
these data sets makes substantial sense. Redesigning data collection systems is fine, provided that some sort of comparison of methods is done. (For example, a vegetation survey at a single site can be conducted using the old and the new methods, and results compared.)

Monitoring programs using less than optimal (i.e., cost-efficient) methods are preferable to none, and periodic cross-calibration with an 'optimal' design can be conducted to understand trade-offs.

Soils tend to be very conservative indicators relative to biota. However, the interaction between biotic crusts and soil integrity at many of the NPS sites argues that soil indicators, measured at a relatively infrequent interval, are warranted. Seep water nitrate concentrations at certain sensitive sites (e.g., the hanging gardens), seem logical as one might expect N enrichment to be potentially threatening those areas.

I think that Figure 11 needs to be clarified. Right now, it shows invasive species as the only "driver" to species of concern and to ecosystem structure and function. I've enclosed an attempt to make managers aware that there are many regional drivers likely to be influencing their systems (see figure below). The point is that sometimes the invader is the consequence, not the cause.

I'm of the personal opinion that much of the invasive species interest is a political smoke screen to distract from the real threats to native biotic diversity. (And, I'm also aware of the exceptions to that statement...but I think they are exceptions.) To quote Hobbs and Humphries (1995): "Much of the plant invasion problem is caused by socioeconomic rather than ecological factors. Attempts to treat the problem will fail unless the underlying causes are identified. Some weed problems may be untreatable under current land uses. In these cases, successful treatment requires radical changes in land use." Our own work now indicates that a "perfectly healthy prairie" is vulnerable to invasion simply because it functions as a seed depository from weeds on adjacent disturbed areas. There may be a lesson here. For vegetation inventory and change studies, a design that evaluates changes at boundaries as well as in the interior of sites may be of interest. This might emphasize a landscape/border issue for the program. This also recognizes an anthropogenic influence that is amplified by transport processes.


Species
of
concern
Regional
species
pool
Ecosystem
structure and
function
Environmental
Drivers
(climate,
atmospheric
chemistry,
visitor use,
management)
Regional
species
pool
Invasives

Dr. Joe Truett's Comments on NCPN Phase I Report, January 2003:

3 January 2003

Joe Truett's comments on NCPN Phase I report.

Mark:

Following are comments on your Phase I report, primarily chapters III and IV, from a landscape-as-wildlife-habitat bias. First, I'll briefly address (in sequence) the questions you posed in your "Review Guidelines, NCPN Phase I Report", then talk about some specifics in more detail.

RESPONSES TO YOUR QUESTIONS

1. Yes, I believe your conceptual framework is generally sound and useful. You've done a remarkable job synthesizing available literature to this end.
2. The framework makes sense, given your goals.
3. The models are sound, I believe. They helped organize my thinking, and I suspect this is true of other panel members as well. The graphics are better than the tables in getting across your points because the tables are so complex. But the tables support the graphics.
4. In terms of wildlife habitat, your approach seems generally transferable to riparian systems as well.
5. Landscape-level processes are certainly important for wildlife.
6. Where does the chapter need to go from here? In our meeting we discussed possible needs for an Executive Summary (already identified in your outline), an Ecological History section, and perhaps some effort at identifying a "reference ecosystem" or desired future conditions. Information you present is extensive and complex. Thus, a focused summary of concepts, perhaps in Exec. Summary, would help.
7. Strengths and weaknesses of materials in Chapter III? The great strength, as noted, is the thorough discussion of concepts and background based on literature reviewed. Excellent work! Potential weaknesses, and perhaps this is partly the science panel's charge to address, relate to the need to (a) explicitly state important assumptions, (b) avoid use of loaded terminology such as ecosystem "health" and "degradation" unless explicitly defined, and (c) provide better criteria to help us judge "good" and "bad" in terms of NPS mandates. You've done the last to some extent (e.g., invasive exotics are bad) and maybe the comments below will stimulate responses to further address this issue.

GENERAL

Philosophical Basis for Defining Health. E.O. Wilson (1998:238) pointed out that opinions differ on whether "ethical precepts, such as justice and human rights, are independent of human experience or [whether] they are human inventions". Ecosystem health stands among these "ethical precepts". I view it as a human invention requiring explicit definition in order to be clearly understood and thus rationally monitored.

Perhaps this should be self-evident but some scientists (e.g., Rapport 1989, Rapport and Whitford 1999) appear to view ecological health as a condition that is intuitively apparent (to at least scientists) and thus somewhat independent of viewpoint. But even should health be an absolute condition determined by God or Gaia and not relative to human values, we have no generally accepted holy writ defining it, except perhaps water and air quality standards, and these may have little ecological meaning beyond human needs. Thus we need to carefully define ecosystem health before trying to monitor it.

I had hoped that you (the NPS) would do this, then we on the science panel would have a relatively easy task. We would be required only to judge whether health as defined by you could be monitored by measuring selected indicators. But if in addition you need us to help define health, here are some ideas to consider:

1. Let us assume that the health of NPS ecosystems is defined primarily by its sustainable utility to humans. (Otherwise we must defer to the presumed viewpoints of other, equally selfish, species.).
2. Let us further assume that the "utility" of Park ecosystems includes mainly their aesthetic appeal but also their use as "laboratories" for humans to better learn how to live sustainably outside parks.
3. This line of reasoning may lead us to various concepts of health such as:
   a. Landscapes as "picture postcards" conforming to visitors' enjoyment or expectations of
      - Scenic diversity: water, trees, grass, rocks, dunes, badlands, and their juxtaposition.
      - Abundance and diversity of wildlife, especially highly visible and charismatic species.
      - Historic (and prehistoric) authenticity, i.e., replication of the "natural" or "pre-industrial" condition.

   b. Soils as "terrestrial sponges" to conserve water, potentially leading to greater scenic beauty, biodiversity, and productivity (see below).

   c. "Biodiversity banks" saving or restoring species or ecosystem types, especially those sensitive to human influences.

   d. "Barometers of productivity" against which non-park ecosystems can be measured.
4. The indicators themselves then might include such things as (a) visual attractiveness of landscapes and biota, (b) soil stability and water-storing capacity, (c) native biodiversity in a historic context, (d) lists of native species "banked" by parks, and (e) productivity surrogates" such as soil fertility, standing biomass of animals, or nutrient turnover rates.
5. We can't have it all. Health, if measured by the indicators suggested in (4), will invariably decline in some categories as it improves in others. For instance, maximizing the abundance of wild herbivores (picture postcard) and thereby elevating the rate of nutrient cycling (barometer of productivity) may reduce the ability of soils to capture and store water (sponge rating). Enhancing the ability of soils to absorb and retain water by removing large herbivores or converting woodland or savanna to grassland could reduce floral and faunal diversity.

6. The point of this rambling is that you or we (or both) need to more clearly define what criteria determine health. This will be a human-biased (perhaps should be NPS-biased) exercise. We need this to make the April workshop more productive.

Need to explicitly state assumptions. Following are some assumptions that seem implicit throughout (and some might have been stated explicitly somewhere in the text), but could better direct our deliberations if summed up front. These relate to the previous section.

1. Biodiversity conservation is an important goal. (If this is true, what aspects are important—species richness on a landscape scale, vegetation or habitat-type dispersion, etc.?)
2. Water and soil conservation are important goals. This seems evident based on some in-text discussions but can it be stated more explicitly and up front?
3. Early historic, pre-cattle is the ideal template for park ecosystem restoration and management. This is implied in numerous places but is it true?
4. Impacts by aboriginal humans were insignificant and thus can be ignored for our purposes.
5. Soil and vegetation changes historically caused by cattle (disruption of soil crusts, reductions in perennial grasses, increases in woody vegetation) are bad because (a) cattle are exotics and associated with humans, and/or (b) cattle impacts lead to undesirable soil, water, and vegetative changes.
6. Exotics are undesirable simply because of their alien origin. Clearly, exotics also may alter ecosystem structure or function in undesirable ways. But what if some instead lead to "improvements" in important processes such as nutrient turnover? Can this make them more acceptable, especially if they fill such a role as good as native species?

Need for "reference" ecosystems as templates. (Related to 3 and 5 above.) Many assumptions about what is good and what is bad in national parks seem to be based implicitly on an idealized vision of the early-historic (but pre-European-settlement) landscape. I believe we need to be more explicit about this, partly because impacts on landscapes and biota by aboriginal Americans probably were much greater than have been generally assumed. For example, late prehistoric human impacts on the Colorado Plateau Parks may have included such things as promotion of perennial grass dominance by purposeful burning (Kay 1995), extensive harvest of woody plants for building materials and fuelwood (Betancourt et al. 1981, 1986), and extermination of large grazers locally or regionally (Kay 1995, Truett 1996, Burkhardt 1996). Views of Mack and Thompson (1982) notwithstanding, evidence that bison inhabited the Colorado Plateau in late prehistoric times (e.g., Mead et al. 1991), in conjunction with the ability of bison (Van Vuren and Bray 1996) and cattle to fare well today in Plateau grasslands, suggests bison on the Colorado Plateau would have been an important component of early-historic ecosystems had not humans exterminated them earlier.

Need to minimize expense. Probably the biggest problem will be to narrow the focus of monitoring to items that will be affordable over time. The budget you identify can't measure very much, especially when distributed over all Plateau parks. Can you give us more guidance on priorities, although I know we touched on this at our meeting? (Also see next paragraph.) Installing instrumentation to periodically (or continuously) measure physical variables (precip., soil erosion loss, soil water content, stream flow, etc.) in test and control areas may be one of the most cost-effective ways to acquire useful data. Next in priority might be periodic aerial

photography (or imagery) to document cover by woody vegetation (trees), landscape-scale type (habitat) dispersion, etc. Then additional funds could be used as available to periodically measure vegetation or fauna (point-counts for birds, aerial surveys for large mammals, pitfall traps for herps, trap grids for small mammals, etc.).
A hypothetical test-control setup as described below may be a cost-effective way to use such measures to detect change over time and infer cause.

Hypothetical Strategy.
(a) Maintain a large exclosure or protected area of the park(s) managed as the ultimate "terrestrial sponge". Keep the anti-sponge perturbations (people, large herbivores, etc.) out to the extent possible.
(b) Burn or otherwise manipulate vegetation in this area to maximize water infiltration and storage and minimize soil loss.
(c) Conduct "perturbation experiments" under various stressor scenarios (heavy trampling by people or herbivores, grazing, etc.) in adjacent, similar areas and measure departure from the optimum "sponge" regime.
This kind of a setup would be amenable to controlled research and thereby could attract outside funding from research institutions.

I hope this helps. Let me know if you want additional input.

Joe

Literature Cited

Betancourt, J.L., and T.R. Van Devender. 1981. Holocene vegetation in Chaco Canyon, New Mexico. Science 214:656-658.

Betancourt, J.L., J.S. Dean, and H.M. Hull. 1986. Prehistoric long-distance transport of construction beams, Chaco Canyon, New Mexico. American Antiquity 51:370-375.

Burkhardt, J.W. 1996. Herbivory in the intermountain West: an overview of evolutionary history, historic cultural impacts, and lessons from the past. University of Idaho, Wildlife and Range Experiment Station Bulletin 58. 25 pp.

Kay, C.E. 1995. Aboriginal overkill and native burning: implications for modern ecosystem management. Western Journal of Applied Forestry 10(4):121-126.

Mack, R.N., and J.N. Thompson. 1982. Evolution in steppe with few large, hoofed mammals. American Naturalist 119:757-773.

Mead, J.I., S.E. Sharpe, and L.D. Agenbroad. 1991. Holocene bison from Arches National Park, southeastern Utah. Great Basin Naturalist 51:336-342.

Rapport, D.J. 1989. What constitutes ecosystem health? Perspectives in Biology and Medicine 33(1):120-132.

Rapport, D.J., and W.G. Whitford. 1999. How ecosystems respond to stress. BioScience 49(3):193-203.

Truett, J.C. 1996. Bison and elk in the American Southwest: in search of the pristine. Environmental Management 20:105-206

Van Vuren, D., and M.P. Bray. 1986. Population dynamics of bison in the Henry Mountains, Utah. Journal of Mammalogy 67:503-511.

Wilson, E.O. 1998. Consilience: the unity of knowledge. Alfred A. Knopf, New York, New York.

Science Panel Comments on April 2003 Vital Signs Workshop

Date: 7 April 2003

From: Mark Miller

To: NCPN Science Panel (Truett, Schmidt, Noon, Seastedt)

Subj: NCPN Vital Signs Workshop, 7-9 April 2003

Thank-you for taking the time to attend and participate in our vital signs workshop in Moab. We recognize that the time investment is significant, and we greatly appreciate the efforts you have made to fit the workshop in your busy schedule.

Here is some guidance regarding the workshop and associated details:

1. Workshop participation – NPS staff at the network and park levels value your scientific perspectives and input. As you know, we are struggling to develop a scientifically credible monitoring program within tight constraints imposed by challenging time schedules and budgetary realities. Your role is to help us maximize the scientific credibility of the program within these constraints. During the workshop, I encourage you to participate as much as possible by contributing insights that help us select a set of vital signs that balances scientific issues and needs with management issues and needs.

2. Written comments – Please provide me with your written comments on the vital-signs selection process (including the workshop and earlier steps such as Delphi), and selected vital signs by Friday May 23rd. (I've tried to consider the fact that the end-of-semester rush is approaching.) In your comments, please address the following questions:

- From a scientific perspective, what were the strengths and weaknesses of the process used by NCPN to identify and select the preliminary set of candidate vital signs?
- From a scientific perspective, what are the strengths and weaknesses of the selected set of vital signs?
- What scientific issues remain to be resolved before we can begin preliminary design work?
- What recommendations can you offer to help us address issues identified above?

Next steps – as indicated during our December 2002 meeting, we will ask you to review and comment on the draft of our Phase II report in late July – early August.

Dr. Barry Noon's Comments on April 2003 Vital Signs Workshop:

Colorado State University
Department of Fishery and Wildlife Biology
Fort Collins, CO 80523

May 22, 2003

Dr. Mark Miller
Northern Colorado Plateau Network
National park Service
2282 S. West Resource Blvd.
Moab, UT 84532

Dear Mark:

As requested, I will provide my candid comments on the Vital Signs Workshop held 7-11 April 2003 in Moab. As was apparent during the workshop there were many topics/approaches proposed by your staff that I agreed with, and several that I disagreed with.

I believe that you and Angela Evenden have done an exceptional job of summarizing the extensive literature on indicator selection for monitoring ecological systems. However, indicator selection is ultimately based on the goals and objectives of the monitoring program. In my opinion, these objectives were never made explicit during the workshop. As I suggested in Moab, I would have had them written in large letters posted in the front of the meeting room. In this way, the participants would have been constantly reminded of the task at hand.

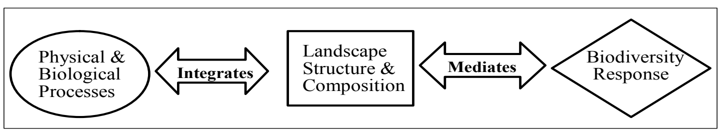
Establishing a set of clear objective statements is difficult, but an essential first step. In your case, one could start with the NPS Organic Act.

> "…to conserve the scenery and the national and historic objects and the wildlife herein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

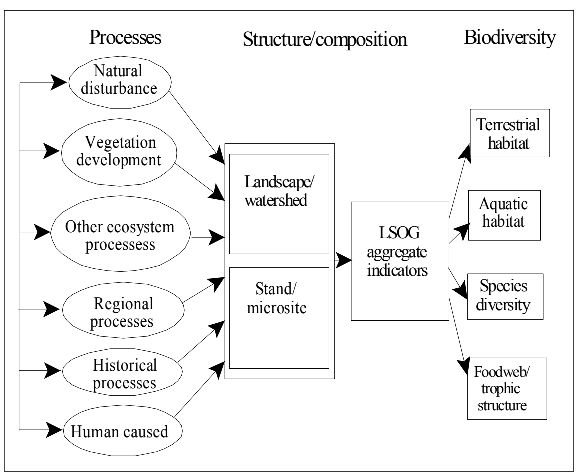
This charge is clearly too vague to provide much guidance. However, the legal mandates in the above phrase could be legitimately interpreted to compel the NPS to conserve ecosystems (the scenery as defined by dominant vegetation communities) and their component parts (wildlife and all other species). Following this line of logic, I would have proceeded in a top-down approach by identifying ecosystems based on some hierarchial classification system. A good example would be the system of ecoregional classification used by The Nature Conservancy (e.g., Groves et al. 2002). This system is based largely on dominant vegetation, but for Colorado Plateau parks should also include soils, geology, and topography. It is hierarchial allowing for the identification of small but functionally unique ecosystems such as springs and seeps nested within larger community types. This approach is in contrast to the approach you adopted which I would characterize as bottom-up.

I would follow this step by identifying those ecosystems that are regionally rare and/or at risk. These ecosystems would receive priority attention during indicator selection. For all distinct ecosystem identified, I would then begin the process of developing a conceptual model for each. The purpose of a conceptual model (usually in the form of a boxes and arrows diagram) is to elucidate the important components (the boxes) and the flows of matter and energy among the boxes (the arrows). There are several good examples of such models in the ecological literature. Some that I have found to be particularly good are those developed to guide restoration of the Kissimmee River in Florida (Trexler 1995).

The approach to conceptual model development for the Pacific Northwest public lands was based on the simple diagram shown below based on distinguishing between processes, structure and composition (physical elements and dominant vegetation), and biodiversity.



Conceptual model structure for identifying indicators

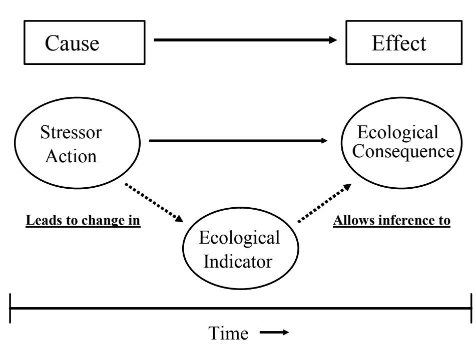


Conceptual models serve many roles: one is to illustrate the linkages among management actions, environmental stressors, and ecological effects, and to provide the basis for formulating and testing causal hypotheses. Most relevant to the Vital Signs initiative maybe the guidance they provide for indicator selection. Indicators can be either process based or element based components of the conceptual model. A further elaboration of conceptual models relevant to Colorado Plateau parks adds state factors based on spatial patterns in soil development (Amundson and Jenny 1997). The state factor approach allows one to conceptualize or predict an "expected state" for an ecosystem which in turn allows one to specify expected values for indicator variables. Possible state factors include (Admundson and Jenny 1997):

State Factors
- Climate
- Parent material
- Topography
- Biota (the set of organisms characteristic of a place)
- Time (since parent material deposition or primary succession)

Stochastic Factors
- Natural
  - Extreme climate events
  - Irruptions of native biota
  - Geological events
  - Lightning fires
- Anthropogenic
  - Human accelerated climate change
  - Introduction of exotic species
  - Land use disturbance
  - Air pollution/atmospheric deposition

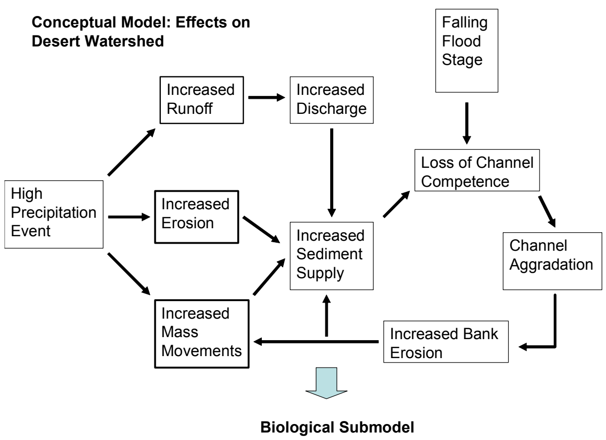
The state factor approach lends itself directly to a stressor oriented approach to indicator selection and monitoring. (I believe a stressor oriented approach should be adopted by the NPS because a) this directly addresses the legal mandates of the NPS, and b) this is the most efficient use of limited funds for monitoring). In terms of the conceptual model, it is important to identify where in the model (ecosystem) the stressor is expected to act, and what ecosystem elements should be most sensitive to stressor action. Further, it is important to discriminate stresses originating outside the boundaries of the park from those that originate internally. This idea is illustrated below.



After development of draft conceptual models for each significant ecosystem in the park, I would begin the process of drafting a candidate indicator set. At this point I would use your vital-sign evaluation criteria (i.e., management significance and utility; ecological significance and scientific validity; feasibility and cost of implementation; and response variability). I would give little weight to existing data sets unless they pass the test of meeting the other criteria. One significant way I might differ from your approach is that I would give great weight to indicators that are sensitive to the action of anthropogenic stressors.

Now some thoughts on the properties of the indicator set. First, the indicators, considered as a set, should be exhaustive of the ecosystems within a given park. Second, within a given ecosystem, the indicators should be mostly complementary in their information content (i.e., minimal redundancy). For example, for a comprehensive indicator species it is important that representatives be selected from all functional groups (producers, herbivores, carnivores, decomposers, etc.). Third, the indicators should be complementary and spanning in terms of space and time. By this I mean that the indicator set for a given ecosystem should encompass a range of spatial scales and, in addition, include indicators that range from fast to slow in terms of their rates of change. Fourth, it is essential that an expected state, or distribution of states, be specified for the ecosystems within the park. Combining this information with the conceptual model allows one to specify expected values for the indicators and to use this process to detect deviations from the expected state. Fifth, the indicator set should, collectively, provide continuous assessment over a wide range and intensity of stresses.

Following is my attempt at an example. It seems to me that one of the most endangered and rare ecosystem types with the Colorado Plateau are riparian ecosystems. These systems are also greatly influence by stressors (inappropriate land use practices) that originate outside of park boundaries. What I have attempted to show below, in the form of a draft conceptual model, is how the physical components of such a system may respond to a natural disturbance event that acts synergistically with external land use practices. The boxes in this figure could be further elaborated to begin the process of listing measurable attributes that subsequently become candidate indicator variables. This conceptual model would then link to a biological conceptual model to help elements of the biota to serve as indicators of disturbance stressors.



I would not be surprise if you thought that little of what I have said above is very useful at this point in the process. However, as I understand where you are in the process, you still need to reduce the set of indicators to a small number. Developing draft conceptual models of your key ecosystems will help you accomplish that task. Assuming you have done this, this is the way that I would proceed:

1) Separate indicators into two broad groups: those that can assessed by remote sensing technology and those that require field measurement

2) Align each candidate indicator with a given ecosystem (many physical indicators encompass all ecosystems)
3) Further identify where in the conceptual model of that ecosystem the indicator resides. Identify what boxes and arrows connect it with the rest of the model. This should indicate both what affects its value and what in turn it affects.
4) Determine if the value of this indicator is affected by the action of one or more stressors. This increases its likelihood of selection.
5) If multiple indicators reside at the same point in the conceptual model determine which has the greatest information content (tells you the most beyond its own measurement value), and which best meets your other screening criteria.
6) Determine if it is now possible to identify a complementary and exhaustive set of indicators for each ecosystem. That is, all boxes and/or arrows affected by stressors should have at least one indicator identified. If not, go to (7).
7) Iterate back to the top until your budget is exhausted.

I hope these comments are somewhat helpful. I am aware of all the creative energy and that you and Angela are putting into this project. I think you have come a long way and that much progress has been made. I look forward to continuing to work with you and the NPS.

Sincerely,

Barry R. Noon, Professor
Graduate Degree Program in Ecology

Amundson, R., and H. Jenny. 1997. On a state factor model of ecosystems. Bioscience 47:536-543.

Groves, C. R. et al. 2002. Planning for biodiversity conservation: Putting conservation science into practice. Bioscience 52:499-512.

Trexler, J. C. 1995. Restoration of the Kissimmee River: A conceptual model of past and present fish communities and its consequences for evaluating restoration success. Restoration Ecology 3:195-210.

<u>Dr. Tim Seastedt's Comments on April 2003 Vital Signs Workshop:</u>

Review of the NCPN Vital Signs activity.
Tim Seastedt 5/20/03

1. *From a scientific perspective, what were the strengths and weaknesses of the process used by NCPN to identify and select the preliminary set of candidate vital signs?*

The construction and review of the Phase I report was a very different exercise from the Delphi and Vital Signs workshop. I was unclear regarding the extent to which NPS staff were asked to use materials from the Phase I report in their selection activity. Regardless, the exercise was critical to find out what was of concern and importance to managers. From that standpoint the Vital Signs Workshop should be regarded as a major success.

I sensed that staff involved in the NCPN saw the Delphi as an opportunity to list any and all indicators or measurements they believed were relevant to the integrity of their respective ecosystems. From this, a very preliminary list of 'attribute/vital signs' was generated. The group was then asked to rank or weight these in relationship to management significance, ecological significance, feasibility and cost, and index of quantitative usefulness of the index, and the relationship between the index and existing data.

It is highly unlikely that any significant site indicator that was on the radar screen of managers was overlooked. From the workshop discussions, there was some indications that interpretations of the ranks and weightings varied among respondents, but those issues were resolved and clarified at the workshop. The qualitative scores of the respective indicators probably is of less importance than some of the attempted ranking efforts of those indicators.

What could be missing, however, are those remotely sensed indicators that might show how NPS units differ in attributes from the regional landscape. These might include a variety of images and electromagnetic scans that could evaluate management activities with respect to climate change and climate change feedbacks. Obviously, NPS managers are focused at "on-site" problems and consider allocation of resources for comparative exercises to be of low priority. Further, these indices are often fairly abstract and likely are of little value to policy makers or managers. Nonetheless, such metrics provide information that shows how park management deviates from the regional non-NPS average with respect to a suite of biophysical measurements, and this work also is essential in understanding how regional changes might be impacting the system. An inventory of national/regional monitoring programs that can be used to provide "an environmental context" for the NCPN effort needs to be assembled.

2. *From a scientific perspective, what are the strengths and weaknesses of the selected set of vital signs?*

The selected list - the indices put on the wish list at the workshop - was extensive. Most would agree it was too extensive. Managers see within their ecosystems 'objects of risk. The causal mechanisms driving biotic change may currently be unknown. Thus, the list likely contains numerous 'responders' but is light on the 'drivers' of change.

The monitoring program has the opportunity to provide insights into the relative sensitivity and vulnerability of species and communities. We have some understanding of the climate stressors but the remaining anthropogenic drivers - both direct and indirect effects - remain poorly known. We should expect lag effects between cause and effect, and we also should expect interaction effects for some of the stressors. (*The Frontiers of Ecology and the Environment* article showing how climate stress could impact beetle outbreak in Utah was a nice example.) I do not recall a discussion of "indices of biotic drivers of vegetation change" (other than cows) in the workshop and now wonder if (or why) we might have missed this.

The preliminary list generated by the workshop therefore is a) likely excessive in terms of the number of indicators given the realities of time and funding and b) heavily weighted towards measuring the responders of change. (Somehow I don't think I've told you something you don't already know here!)

3. *What scientific issues remain to be resolved before we can begin preliminary design work?*

The preliminary design work seems to be well underway. The work that generated the excellent documents on the NCPN Phase I report, should be continued. You have a compilation of existing databases. Can any trends analysis of 'important parameters' be calculated at this point in time? You have the current list of species at risk. From the extant information, someone needs to make a statement of what we know and don't know about each system. While this activity is seen as a science assessment, it should then be followed with an exercise to translate these findings for policy makers (e.g., the superintendent advisory group) into defensible, relevant, and readily interpreted information. What, if any, decision/management actions might be associated with the data resulting from this effort?

4. *Recommendations to address issues identified above*.

Allocate resources initially to conduct an exhaustive analysis of existing data sets, particularly those with any time series data. This exercise should be followed with a "so what?" summary for policy makers. Make sure that the program will have ongoing analysis associated with data collection. A monitoring program should not be considered something set into stone, and changes based upon rigorous analyses of data are appropriate. After 24 years of LTER-type monitoring, I've found that any time series measurement of any indicator will tell an interesting story. This exercise has, to date, attempted to identify 'the important stories' relative to a clear set of identified goals, and the process must be designed to be somewhat open-ended to fulfill that mission.

I sensed that final indicator selection involves the identification of what is to be done by other agencies or other mandated activities, and use the vital signs program to fill essential gaps. It's perhaps important, therefore, that this be very explicitly acknowledged in that programmatic changes elsewhere may impact this program.

The Phase I activities have attempted to identify critical information needs and gaps, and the workshop provided the mechanism to frame those data needs in terms of identified concerns of managers. The outcome of this exercise is to be a balanced program (with a diversity of categories of vital signs), with specific indicators selected upon criteria of sensitivity and relevance to the NPS mission.

Serious triage is required to reduce the network-wide indicators down to a doable activity given budget constraints. Be explicit that this program does not attempt to measure everything of importance, but rather provides a robust index that can be used to document biotic change and environmental quality issues of the participating units. The scientist in me urges you to select the most important parameters relative to ecosystem sustainability concerns. Equally relevant is the need to select those parameters that are clearly defensible as sensitive indicators that provide information of relevance, concern and interest to policy makers. To date, this effort appears to be on course.

Dr. Joe Truett's Comments on April 2003 Vital Signs Workshop:

22 May 2003

TO: Mark Miller
FROM: Joe Truett
SUBJECT: Comments on NCPN Vital Signs Workshop

Here are my comments on the vital signs selection process and results thereof. These are keyed to the four topics you identified in your letter to the NCPN Science Panel dated 7 April 2003.

**From a scientific perspective, what were the strengths and weaknesses of the process used by NCPN to identify and select the preliminary set of candidate vital signs?*

The process included (1) the science panel's 17 Dec 2002 meeting to evaluate the panel's role and the Phase 1 report, (2) written comments by science panel members on the Phase 1 report, (3) the NCPN Delphi electronic survey, and (4) the 7-9 April workshop. I'm attaching for reference my written comments on the Phase 1 report, which I sent you in early January 2003. The following new material will, I hope, complement but not unnecessarily duplicate those comments.

- Strengths
  1. Perhaps the greatest strength of the process was the background information synthesized by NPS in its Phase 1 report. You are to be commended for that effort. It helped educate science panel members and others, and I suspect it enhanced your own ability to evaluate responses to the Delphi survey and facilitate the April workshop.
  2. Another strength, though at times clearly difficult to deal with, was solicitation of a broader scientific input via the Science Panel and through the Delphi process. (More on the difficulties of doing this appears under "Weaknesses" below.)
  3. Participation by representatives from individual parks in the April workshop clearly strengthened the process. I believe additional interaction with them by you will be needed.
  4. Finally, the NPS and especially Mark Miller conducted the April workshop remarkably well given its brevity, the ambitious amount of material to cover, the number of participants, and disruptions by some of us who sought to amend the process as it played out.
- Weaknesses
  a) Solicitation of input from numerous people via the Delphi process, although conceptually a strength, undoubtedly amplified the difficulty of selecting useful vital signs. The sheer number of opinions would be difficult enough to deal with. Adding to this the disciplinary biases, inadequate backgrounds, and probable lack of in-depth reflection by many participants must have resulted in a daunting amount of information of sometimes questionable value.

b) Related to (a) above, I question whether the Delphi process was well-suited to the vital signs selection process. With all due respect to those who responded, selecting the best vital signs from among the many options possible requires a level of experience and a focus of thinking not common even among well-trained scientists. To mentally synthesize the broad information base applicable to monitoring, then winnow the useful from the possible, is a much different and more complex problem than focusing on specific research or management problems. A less democratic but more effective approach might have been to solicit input from a select few with highly relevant experience in ecosystem monitoring, impact assessment, or landscape ecology.

c) The April workshop was not long enough. The predictable tendency for some workshop participants to posture and joust the first day or two, the substantial number of sometimes unprepared participants, and the complexity and novelty of issues, quickly consumed the time available. Having said this, I don't know how it could have been done better without substantially lengthening the workshop, inviting fewer participants, and focusing on a shorter initial list of candidate vital signs.

d) The strategy for conducting the workshop was criticized by some, but I question whether another strategy would have worked any better. The workshop served to prepare people from individual parks for a follow-up visit from Mark, which probably would have been needed in any case given the constraints described in c) above.

**From a scientific perspective, what are the strengths and weaknesses of the selected set of vital signs?*

My attached response to the Phase I report identified some of the strengths and weaknesses that I believe remain.

1. The major strength is that most vital signs were selected based on reliable scientific information. I believe the in-house expertise of the NPS did much to ensure this by preparing an excellent Phase I report and selecting top-quality outside participants. Both the initial 1-day workshop (December 2002) involving science panel members, and the larger April 2003 workshop, convinced me good science was at work.

2. The major weakness is that the list of vital signs that remained at the end of the April workshop still was far too long. A long list might be OK if only a few vital signs are selected for monitoring at each park, that is, many vital signs are measured in total but each park monitoring program is rather simple. However, if the same vital signs are to be monitored in all Colorado Plateau parks, the list needs to be severely shortened.

3. Some general problems not addressed in depth at the workshop are the same ones I described earlier in the (attached) Comments on Phase I Report: (a) What constituted ecosystem "health" was not explicitly stated; (b) Some important assumptions were not explicitly stated; (c) Whether and which historic condition was being used as the model for good health was unclear.

4. For many of the vital signs, sorting human-caused from natural variation will be difficult. Although some monitoring approaches we touched upon (e.g., cross-fence comparisons at

park boundaries) will help sort these out, many cause-effect relationships will remain difficult to demonstrate. Normal temporal and spatial variation will contribute to this difficulty, given in particular the limited amount of funding available.

**What scientific issues remain to be resolved before we can begin preliminary design work? and*
** What recommendations can you offer to help address these issues?*

1. Use in-house expertise and consultation with individual park managers to substantially reduce the list of "vital signs" generated at the April workshop.
2. In collaboration with individual parks, separate this reduced list into "plateau-wide" vs. "park-specific" signs.
3. Decide whether and how statistical methods will be used to make comparisons and infer cause-and-effect.
4. Evaluate the relative important of physicochemical vs. biological vital signs given general NPS objectives. Physical and chemical measures such as precipitation, temperature, and water chemistry may often be more readily and less expensively collected, and baseline or historical measures of such measures may already exist. Short-term studies (see 7, below) may then relate biological changes to physicochemical changes.
5. Evaluate the relative importance of population-level and landscape-level vital signs with respect to biota. (Remote sensing technology may help provide inexpensive measures of landscape-level phenomena.)
6. Evaluate the relative importance of monitoring short-term (months, years) vs. long-term (decades, centuries) changes in the context of NCPN monitoring objectives.
7. Decide how funding will be strategically applied over time to implement the monitoring program. For example, physical, chemical, and landscape-level vital signs may be adequately measured within NPS budget constraints but population-level signs may not. If such is the case, opportunistic short term studies funded by outside entities (grants, universities, etc.) may be used to elucidate cause-effect relations between plant/animal populations, physicochemical changes, and human perturbations. (See also "Hypothetical Strategy" at end of attached comments on Phase 1 report).

In short, much remains to be done, but I think your in-house expertise is up to the task. You have involved outside expertise (Science Panel, Delphi surveys) all you need to. As is proper in a representative democracy, you have heard our input but cannot include us all in making the final decisions.

Joe C. Truett, Ph.D.
Science Panel

Science Panel Review Comments on NCPN Phase II Report (17 August Review Draft)

Date: 17 August 2003

From: Mark Miller

To: NCPN Science Panel

Subj: Review of 17-August DRAFT NCPN Phase II Report

Folks --

Attached is a review draft of our Phase II report, in which we identify and prioritize "vital signs" for the network. We are required to obtain "peer review" of the report prior to our final submission to the regional office (mid September) and Washington office (30 September). As our independent science review panel, we are asking you to provide this official review. We can provide no financial compensation for this review, but I'm sure that you will gain great satisfaction nevertheless. I will do my best to respond and address your comments in the final version of the Phase II report.

The attached draft is not quite complete. Some narrative material that will accompany park-specific vital-sign tables remains under development, but the remainder of the document is complete. I'm confident that there is sufficient material for you to judge what you do and do not like about what we have accomplished to date.

The entire document is about 270 pages long, but most of it consists of appendices. You should focus on the body of the report itself, although Appendices A and B provide important supplementary information concerning the vital-sign identification process that we enjoyed over the past nine months. I encourage you to look over those appendices as well -- particularly those of you who were unable to attend the exciting workshop in April. Appendix A includes some comments on issues that were encountered during the workshop -- you may be interested in these. Other appendices are provided for your information, and you may address them in your review comments if you wish.

Review Content -- Our objective is to develop a scientifically credible monitoring program that satisfies NPS goals for vital-signs monitoring. We interpret these goals in the context of overall NPS management policies concerning the maintenance and restoration of "ecosystem integrity" on park lands. These ideas are all restated in the report. Your role is to provide a check on the scientific credibility of our approach. In your view as independent scientists with expertise in monitoring, are we on track thus far? In what ways are we succeeding, and in what ways are we failing in the development of a scientifically credible monitoring program? With respect to our failures, what recommendations can you offer to help us get back on track?

There are serious constraints in this program -- particularly with respect to money and time. I am conscious of the fact that, in many cases, we have not done a very good job in addressing your previous comments. In my view, this is largely a consequence of our challenging time schedule. You may or may not agree with that view. In any case, I encourage you to take this review opportunity to speak to the larger audience of the NPS I&M Program as you see fit. All of your comments (including previous comments on Phase I and the workshop) will be included as an Appendix to the Phase II report. Your comments may help other networks in addition to ours.

<u>Dr. Jill Baron's Review Comments on NCPN Phase II Report</u>
[Note that page number cited below refer to the review draft dated 8/17/03 and not to this final report.]

Comments on the PHASE II report for monitoring vital signs for the NPCN.

Mark,

Overall, I agree fully with the philosophy and effort that will build the Northern Colorado Plateau Inventory and Monitoring Program. I think you and everyone who has helped have done an admirable job of sifting through the many important aspects of natural resource monitoring to clearly identify priorities. I also appreciate the descriptions up front that clearly define what the indicators are and are not, as well as the philosophy behind the choices of indicators. I think these will prove immensely valuable in years to come, to remind people of why and how these specific elements were chosen. I have listed some specific comments below, but one remaining general concern is that I did not see anywhere a description of how the monitoring data will be analyzed and assessed on a regular basis. The extensive process of indicator selection has been very important, but indicator identification and sampling only begin to get to the actual use of these data, so my opinion is that we are only about 2/3 of the way to actually developing the I&M process.

Specific comments:
p. 4. There is a discussion at the top of the page of perspectives by which resource significance can be established. Ecological Functionality (#2), includes air quality, soil quality, water quality, crusts, and aquatic ecosystems. I wonder if there was a discussion of including flow regime as an additional critical process? Flow regime is different from water quality and existence of riparian, wetland, and aquatic ecosystems, and in fact is one of the essential processes needed to sustain such ecosystems.

p. 6, Table 2. The first management objective is the "reduce", and the third is to "maintain or restore". Shouldn't the second objective be to "minimize," instead of "understand?"

P. 9 continues a discussion of feasibility and cost of implementation, with a list of reasons for selection of specific vital signs. I agree with all of them, but in keeping with the suggestion above to include evaluation and interpretation along with sampling and analysis, I suggest interpretation be added to the 4th bullet (full costs....). I realize analysis is there in the list of activities, but it is different than going the final step of asking and reporting what the data actually mean.

p. 36, priorities of vital signs for Capitol Reef. I realize this is beyond my control, since I wasn't at the workshop, but I was surprised to see tinaja status ranked as only moderately important. I realize their flashy hydrology creates conditions that encourage opportunistic riparian and aquatic communities, but livestock or visitor overuse could encourage erosion and loss of wetland communities surrounding them.

p. 65, CARE again. The park did not list these unique water bodies at all for monitoring, proposing to sample only flowing waters for water quality. I think it is a mistake to ignore these aquatic resources entirely.

I look forward to working with the NPCN group as we move into Phase III, implementation.

Sincerely,

Jill Baron
Ecologist, USGS
5 September 2003

<u>Dr. Tim Seastedt's Review Comments on NCPN Phase II Report</u>
[Note that page number cited below refer to the review draft dated 8/17/03 and not to this final report.]

Comments on: "Northern Colorado Plateau Vital Signs Network and Prototype Cluster Plan for Natural Resources Monitoring, Phase II, 17 August 2003

T.R. Seastedt, 9/2/03

Strengths of the report:
1) The use of the Chapin et al. 1996 rendition of the Jenny (1980 and earlier) model is viewed as the most powerful approach currently available to provide an overarching conceptual framework for the vital signs network. The Harwell et al. 1999 analysis also puts the present effort into a relevant context. The current document very appropriately uses "the best of" the most recent ecological management and ecological monitoring literature in generating the proposed network.

2) This is an important document, both as a benchmark in the creation of a relevant, functional monitoring program, but also as an historical document of the process involved in the creation of this activity.

Recommendations:
While I'm sure there are plans for this, an executive summary for administrators and policy makers is in order. A similar overview (and users guide) might be useful for those park managers that were not involved in this activity. The discussion of Delphi to Darkness rankings will overwhelm most readers. At least, it overwhelmed me!

I realize that the funding of this monitoring effort will be a creative enterprise. I would also urge you to use this opportunity to prepare a report such as "Science needs of the NCP NPS" and see if you can't attract some science partners via the NPS science funding programs or outside sources to generate some baseline data sets.

Some specific comments: (Exactly why these were chosen and others were not, I cannot fathom. In any event, the 278 pg document should be regarded as a benchmark to be revisited and, as necessary, updated and revised. "As necessary" is likely to be a high probability even for any long term monitoring activity.)

Pg 6, Table 2. Given the organization of the section on invasives, I would argue the Management objectives should read: "*Prevent new establishment of non-natives and reduce the spatial extent and abundance of established non-native species to levels necessary to achieve other conservation goals."* The point is that you don't want to waste time or money killing weeds you don't need to kill.

Pg 14, second paragraph from the bottom. I still disagree with this procedure. While measures should not be penalized because nobody thought of them before, the fact that extant data sets exist greatly enhances the value of a similar (repeat) sampling. As I recall some historical data sets have failed to live up to the goals that were initially associated with those data collections.

However, goals change, while the value of historical data only increases. As often is the case, data for one topic can become valuable "proxy data" for other vital signs.

Pg 50. I believe that John Moore (Northern Colo. Univ) has done some soil biodiversity work that has relevance to "cave soil quality".

Pg 172. I still like my modification of Figure E-1 better (attached below)! The May 2003 BioScience article by Mark Davis makes the argument that plant competition is not going to threaten most species. This is a hypothesis that is not something NPS should be testing, however, so on NPS lands the "kill it now, study it later" philosophy is appropriate.

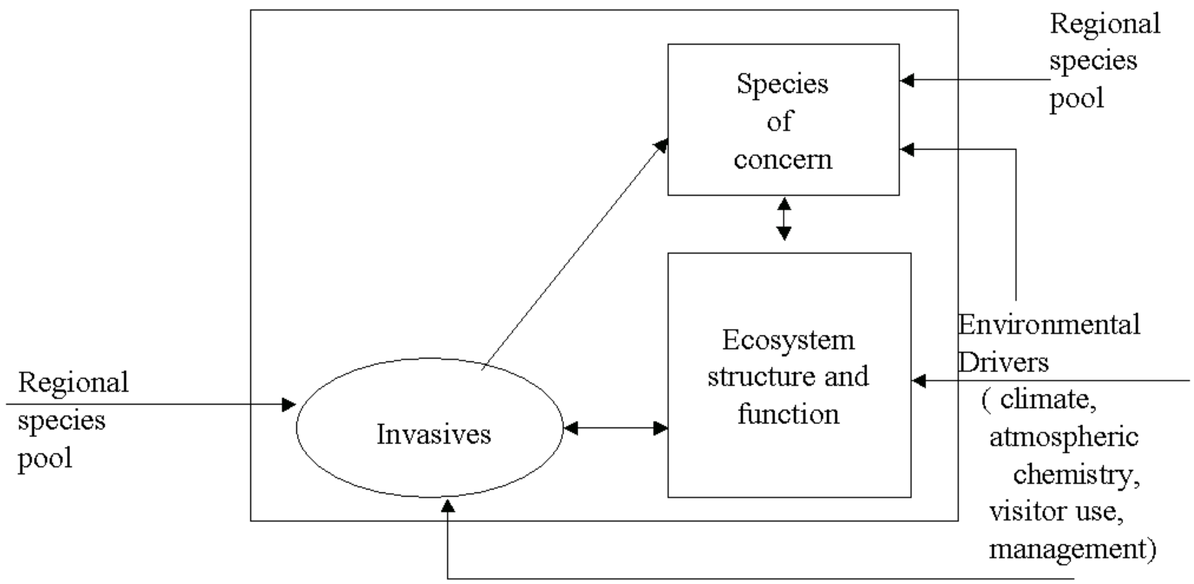
Pg 174. I really like this figure. Isn't ammonium also on your list of airborne 'pollutants'?

Pg 196. Can anybody tell me where the concept of "Best Management Practices" came from? And, who's in charge of the quality control behind this list? I finally was shown the BMPs for weeds of the Colorado Front Range. What I saw was, well, out of date. BMPs need to be out there where they can be constantly inspected, commented upon, and updated.

Pg 197. This concept of disturbance is a bit out dated and should be replaced. Natural disturbances are usually viewed as discrete events that occur periodically, within a defined historical range of variability. New disturbances are events that either have not occurred or are now occurring at frequencies not previously recorded. This makes fire return intervals of four years in the Great Basin areas "new" disturbances since the HRV for fire had an average return interval of about 70-80 years or so?

Pg 224. This figure is very hard to read. I think I like it...but it hurts my eyes.

Pg. 225. While state and transition models are useful, recall that these (at least the ones I've played with) are closed systems. You can only change states, not create new ones. What we're doing through the variety of global environmental change mechanisms identified herein is creating new states meaning, that, such models become heuristic tools only after the fact.


Regional
species
pool
Species
of
concern
Ecosystem
structure and
function
Environmental
Drivers
(climate,
atmospheric
chemistry,
visitor use,
management)
Regional
species
pool
Invasives

Dr. Joe Truett's Review Comments on NCPN Phase II Report

[Note that page number cited below refer to the review draft dated 8/17/03 and not to this final report.]

Review:

NORTHERN COLORADO PLATEAU VITAL SIGNS NETWORK
AND PROTOTYPE CLUSTER PLAN FOR
NATURAL RESOURCES MONITORING

PHASE II

by

Joe Truett
Turner Endangered Species Fund
P.O. Box 211
Glenwood, NM 88039

to

Mark Miller
Ecologist, Northern Colorado Plateau Network
National Park Service
2282 S. West Resource Boulevard
Moab, UT 84532

22 August 2003

The following review assesses the scientific credibility of the approach used for developing a "vital signs" monitoring plan for Northern Colorado Plateau Network (NCPN) national parks. This review focuses on the Phase II Report, a 264-page document prepared by the NCPN staff in Moab, Utah. That report built on the scientific literature, a series of meetings and workshops, and an internet-based "Delphi" survey.

Incorporated in this review are relevant parts of 2 previous critiques from me to Mark Miller of NCPN: (1) comments on the Phase I Report submitted 3 January 2003 and (2) comments on the "vital signs selection process" submitted 22 May 2003. The present review focuses primarily on the Phase II Report body. I address in sequence the three questions asked in Mark Miller's letter requesting this review (dated 17 August 2003):

- Are we on track thus far?
- What are the successes and failures of the process?
- How can we improve the process?
-

Are We On Track?

Yes. You have used a sound approach that involved an extensive literature review, critiques by a science review panel, workshops involving science panel members and NCPN personnel, and a Delphi query to a broad array of experts. As I noted in earlier comments, your review of background information was exceptionally well done. I believe it not only helped focus efforts of participants but also served to better educate all involved, including science panel members.

What Are The Successes?

Important successes included the following:

- In-depth review and application of relevant literature.
- Development and adherence to a sound conceptual framework.
- Use of models, especially in graphic form, to convey concepts.
- Promotion of free exchange of ideas in workshop format.
- Sincere efforts to solicit and incorporate ideas from all participants in the process.
- Remarkable progress in synthesizing a coherent document from a plethora of facts and ideas that at times seemed to border on chaos.
- Application of good judgment to substantially reduce the complexity of options to simpler sets of indicators and measures more in line with funding constraints.

Overall, this exercise in vital signs selection has been an outstanding success. The NCPN staff in Moab can take credit for this success by their background preparation, in-depth knowledge of the issues, and ability to motivate people in workshop format. Having in the past participated in several programs that planned large, multidisciplinary studies, I felt comfortable with the rate of progress. The struggle with ecosystem complexity and differing viewpoints on strategy is in my experience common to such efforts. NCPN staff moved forward quickly but on a sound scientific basis to produce a highly credible Phase II report.

What Are The Failures And How Can We Improve?

The process to date has not "failed" in important ways. But it might have been (and still could be) strengthened in a few areas as described below.

1. Clarify Assumptions and Definitions Related to Ecosystem Health.

As noted in my comments of 3 January 2003, I believe ecosystem "health" and related concepts such as ecosystem "integrity", "quality", and "condition", must be explicitly defined to be measurable because they are human inventions and not absolute qualities. The Phase II Report recognizes this possibility (e.g., see "Sustainability" section on page 3, and "vital signs as ecological indicators—or not?" at bottom of page 107), and offers more or less explicit definitions (Appendix J). Common use of the adjective "desired" to refer to ecosystem condition goals further signifies the importance of judgment.

But ambiguities remain, as exemplified in the Appendix J definitions of such terms as ecological integrity, ecosystem health, and indicator. I believe these ambiguities may result in part from trying to accommodate sometimes contradictory assumptions about ecosystem development and about optimum ecosystem states. Because these assumptions will influence monitoring success, a couple of contradictory ones may be worth summarizing here.

The implicit assumption that ecosystem components (species) co-evolved in situ and thus "belong together" in the parks in some semblance of their early historic condition seemed often in this exercise to underlie the concept of ecosystem health. Though usually not explicitly stated, this view is implied in the list of vital signs in the Phase II report, especially those in the Biotic Integrity category (Table 5). Indeed, the NPS mandate for park managers to preserve natural resources "unimpaired for future generations" implies maintenance of some given state.

In contradiction to such an assumption, a growing body of information indicates that the early historic condition (or condition at any other point in time) is only one of many along a time gradient extending before as well as after the advent of European peoples (Hunter et al. 1988, Johnson and Mayeux 1992, Young et al. 2001). Species composition, for example, can change rapidly even in the absence of humans, casting doubt on the concept of co-evolution and the idea that ecosystem status at any one time serves as the best model of health for the longer term.

The Phase II report does an admirable job of balancing these two paradigms without exploring them in depth. But I believe some of the ambiguities in definitions and discussions could be explained and partly remedied by at least a short description of these opposing views and their implications.

2. Reduce or Further Prioritize "Vital Signs" Lists to Fit Slim Budgets

The Phase II report's Chapter III, "Vital Signs", represents major progress in winnowing important candidates for monitoring from among the many that remained at the end of the 7-9 April workshop. The tables in this chapter clearly display the vital signs and their relative priorities. I believe, however, that the costs of monitoring even a modest proportion of these will be prohibitive, especially if you expect to assign cause to any changes documented. The prioritization scheme you've used helps, but I'd guess there are far too many high-priority tasks (xxx) to be funded.

Acquiring outside funding for some of the monitoring tasks may help, as you indicate. But the uncertainly of such funding (and perhaps even NPS funding given the continuing budgetary drain of the war on Iraq to the tune of $5 billion per month) may preclude the regularly repeated measures needed for some kinds of monitoring. The credibility of results thus can be affected.

In short, I believe more effort will be needed to try and focus on a very few cost-effective and "information-rich" monitoring tasks in each park.

Literature cited

Hunter, M.L., Jr., G.L. Jacobson, Jr., and T. Webb III. 1988. Paleoecology and the coarse-filter approach to maintaining biodiversity. Conservation Biology 2(4):375-385.

Johnson, H.B., and H.S. Mayeux. 1992. Viewpoint: a view on species additions and deletions and the balance of nature. Journal of Range Management 45:322-333.

Young, T.P., J.M. Chase, and R.T. Huddleston. 2001. Community succession and assembly. Ecological Restoration 19(1):5-18.

Date: 18 September 2003

To: Jill Baron, NCPN Science Panel Member

From: Mark Miller

Subj: NCPN Responses to Phase II Review Comments

Thank-you for taking the time to review the 17 August draft of the NCPN Phase II Report. Following are responses to your 5 September 2003 review comments:

1. *...one remaining general concern is that I did not see anywhere a description of how the monitoring data will be analyzed and assessed on a regular basis.*

   Response: We appreciate the importance of this issue. Data analysis and reporting will be major components (Ch. VII) of the Phase III report. Each monitoring component included in the Phase III report will include the following elements: sampling design, sampling protocols, data-management protocols, and explicit plans for data analysis and reporting.

2. *[In relation to the discussion of ecological functionality as criterion for establishing resource signifance], I wonder if there was a discussion of including flow regime as an additional critical process?*

   Response: The material to which you refer was developed during preparation of the Phase I report (networks were instructed to identify their 'most significant' resources). Although there was no explicit identification of flow regime as a critical process for emphasis at that time, we did indicate in both the Phase I and Phase II reports that the ecosystems identified as 'significant' (including riparian, aquatic, and wetland systems) necessarily encompassed all of the ecological processes and conditions required to sustain the existence of those ecosystems. During the Phase II process, we did explicitly identify "stream flow regime" as a critical process for sustaining riparian, wetland, and aquatic ecosystems. This is a high-priority vital sign for the network as a whole, as well as for individual parks with significant lotic systems. For groundwater-dependent systems, the equivalent vital sign is described as "groundwater dynamics" – which is intended to encompass the concept of groundwater flow regimes (also a high-priority vital sign).

3. *Table 2. The first management objective is the "reduce", and the third is to "maintain or restore". Shouldn't the second objective be to "minimize," instead of "understand?"*

   Response: Good point. The objective has been revised to read "Understand and minimize...."

4. *[Pertaining to vital-sign evaluation criteria used during Delphi round 2], ... in keeping with the suggestion above to include evaluation and interpretation along with sampling and*

analysis, I suggest interpretation be added to the 4th bullet (full costs....) [beneath general evaluation heading of Feasibility & Cost of Implementation].

Response: Your point is well taken that the final steps of data interpretation and reporting are critical and beyond the scope of 'data analysis.' The network will need to plan and budget to ensure that sufficient resources are available for these final steps. No change was made to the referenced text in the Phase II report since this material was reporting the criteria used during the Delphi process and subsequent steps.

5. *...I was surprised to see tinaja status ranked as only moderately important [for Captiol Reef]. I realize their flashy hydrology creates conditions that encourage opportunistic riparian and aquatic communities, but livestock or visitor overuse could encourage erosion and loss of wetland communities surrounding them.*

   Response: The relative priority of tinaja monitoring at Capitol Reef has been reevaluated. Although we have retained the medium (xx) priority rating for tinajas in this report, we hope to evaluate monitoring priorities more thoroughly in conjunction with an inventory and risk-assessment project that currently is being developed for springs, seeps, hanging gardens, and tinajas in cooperation with the Southern Colorado Plateau Network. Your comment prompted us to consider the identification of tinaja systems as vital signs for other network parks under the category of "status of unique communities." Zion, Arches, and Canyonlands adopted this as another vital sign and all assigned a medium (xx) priority ranking.

6. *[In relation to water-quality monitoring for Capitol Reef] -- The park did not list these unique water bodies at all for monitoring, proposing to sample only flowing waters for water quality. I think it is a mistake to ignore these aquatic resources entirely.*

   Response: Good comment. Tinaja systems have been incorporated in the water-quality tables for Capitol Reef, Arches, Canyonlands, and Zion.

Date: 18 September 2003

To: Tim Seastedt, NCPN Science Panel Member

From: Mark Miller

Subj: NCPN Responses to Phase II Review Comments

Thank-you for taking the time to review the 17 August draft of the NCPN Phase II Report. Following are responses to your 2 September 2003 review comments:

1. *While I'm sure there are plans for this, an executive summary for administrators and policy makers is in order.*

   Response: An Executive Summary has been included in the final draft.

2. *I would also urge you to use this opportunity to prepare a report such as "Science needs of the NCP NPS" and see if you can't attract some science partners via the NPS science funding programs or outside sources to generate some baseline data sets.*

   Response: This is a great suggestion. In the Phase I report, we indicated that "Future iterations of the monitoring plan should include a section outlining a [science] strategy for meeting the research needs of monitoring" (Evenden et al. 2002:63). Due to workloads, we failed to carry through with that statement by including such a strategy in the Phase II report. It's still on the agenda.

3. *Table 2. Given the organization of the section on invasives, I would argue the Management objectives should read:* "Prevent new establishment of non-natives and reduce the spatial extent and abundance of established non-native species to levels necessary to achieve other conservation goals." *The point is that you don't want to waste time or money killing weeds you don't need to kill.*

   Response: This is another good suggestion. The text has been revised accordingly.

4. *[Regarding the group decision made during workshop to exclude existing data and programs from contributing to overall evaluation scores for candidate vital signs] – I still disagree with this procedure. While measures should not be penalized because nobody thought of them before, the fact that extant data sets exist greatly enhances the value of a similar (repeat) sampling. As I recall some historical data sets have failed to live up to the goals that were initially associated with those data collections. However, goals change, while the value of historical data only increases. As often is the case, data for one topic can become valuable "proxy data" for other vital signs.*

Response: Although 'existing data and programs' were not included in the final evaluation scores used to rank candidate vital signs during the workshop, they were major factors considered during the later identification and prioritization of vital signs for individual parks. This is implicitly indicated in the network overview as well as in park-specific narratives. In response to your comment, I've added some text to clarify this point.

5. *I believe that John Moore (Northern Colo. Univ) has done some soil biodiversity work that has relevance to "cave soil quality."*

   Response: Thanks. We'll follow-up on this tip.

6. *[Regarding Figure E-1 in Appendix E depicting relationships among prototype themes] -- I still like my modification of Figure E-1 better (attached below)! The May 2003 BioScience article by Mark Davis makes the argument that plant competition is not going to threaten most species. This is a hypothesis that is not something NPS should be testing, however, so on NPS lands the "kill it now, study it later" philosophy is appropriate.*

   Response: Originally, this figure was intended only to indicate general relationships among prototype monitoring themes – i.e., it was not envisioned as an ecological conceptual model *per se*. However, I can see the value in adding the clarifications you've suggested. Your model has been added as part b of the figure in Appendix E (and you have been cited as the source!).

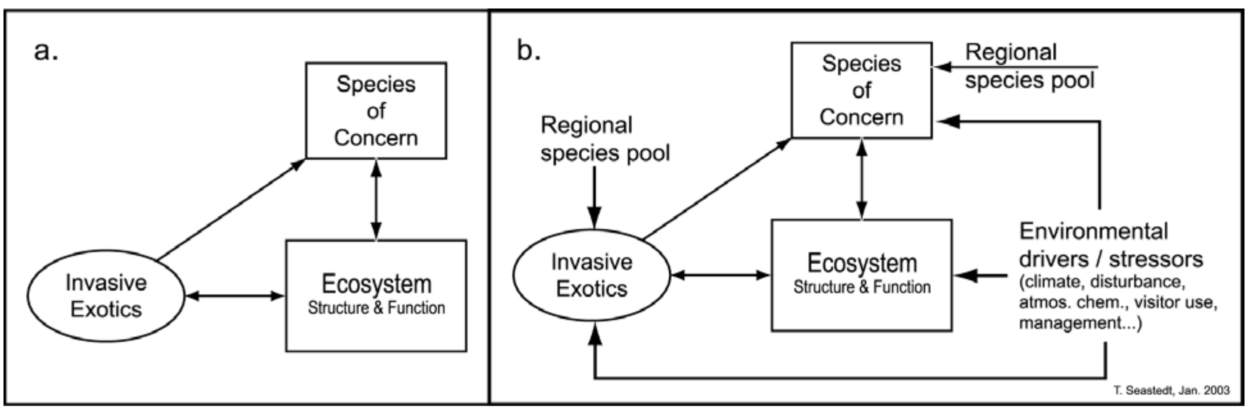


Figure E-1. Monitoring themes (a) of the Northern Colorado Plateau Prototype Cluster, and (b) ecological factors influencing these themes.

7. *[Regarding Figure E-2 in Appendix E depicting the Chapin-Jenny model and stressors affecting NCPN ecosystems] – I really like this figure. Isn't ammonium also on your list of airborne 'pollutants'?*

   Response: Good suggestion. I've edited the figure to include ammonium.

8. *[Regarding Appendix F] – Can anybody tell me where the concept of "Best Management Practices" came from? And, who's in charge of the quality control behind this list? I finally was shown the BMPs for weeds of the Colorado Front Range. What I saw was, well, out of*

date. BMPs need to be out there where they can be constantly inspected, commented upon, and updated.

Response: I'm not sure where the concept came from, but your point is well taken. The version presented in Appendix F is a draft and has not yet been subjected to full peer review. We acknowledge that it will be important to revisit, update, and revise all aspects of the plan as necessary on a periodic basis (as you indicated elsewhere in your comments) – including this 'best-management-practices' component.

9. *[Regarding discussion of* disturbance *concept in Appendix F] – This concept of disturbance is a bit out dated and should be replaced.*

   Response: Thanks for catching this. The text has been revised accordingly.

10. *[Regarding Figure I-4 in Appendix I depicting draft ecosystem characterization model for arid / semiarid systems] – This figure is very hard to read. I think I like it...but it hurts my eyes.*

    Response: I've done what I can to increase the size of the figure in the final draft.

11. *[Regarding use of state-and-transition models as tools in development of monitoring program] – While state and transition models are useful, recall that these (at least the ones I've played with) are closed systems. You can only change states, not create new ones. What we're doing through the variety of global environmental change mechanisms identified herein is creating new states meaning, that, such models become heuristic tools only after the fact.*

    Response: In her review of the Phase I report, Jill Baron made a similar comment regarding the *post hoc* nature of state-and-transition models. I recognize that these are primarily retrospective models describing our current understanding of past within- and among-state dynamics. To the degree that the future is unlike the past (highly probable), I'm cognizant that retrospective models will not fully meet our needs. Rather than scrapping them, we first need to assess the strengths and weaknesses of current models in terms of their ability to help us think about the future. We hope that you'll continue to prompt us about these issues as the program develops.

Date: 18 September 2003

To: Joe Truett, NCPN Science Panel Member

From: Mark Miller

Subj: NCPN Responses to Phase II Review Comments

Thank-you for taking the time to review the 17 August draft of the NCPN Phase II Report. Following are responses to your 22 August 2003 review comments:

1. *Clarify Assumptions and Definitions Related to Ecosystem Health. ...the NPS mandate for park managers to preserve natural resources "unimpaired for future generations" implies maintenance of some given state. ....In contradiction to such an assumption, a growing body of information indicates that the early historic condition (or condition at any other point in time) is only one of many along a time gradient extending before as well as after the advent of European peoples....*

   Response: Your comments pertain to a complex mixture of ecological theory, environmental philosophy, and agency management policies. I agree that the monitoring program is strengthened by clarity of concepts and assumptions pertaining to the various aspects of this milieu. We still have a long way to go in this regard, but I believe that we have made progress and that the current document is less clouded with contradictions and ambiguities than you suggest. I have not made any changes to the text of the Phase II report on the basis of your comments, but here I briefly address a few of the interesting issues you raised.

   On the maintenance of ecosystem "states" – We (NCPN and NPS generally) are aware of the dynamic nature of ecosystems and community assemblages over wide ranges of temporal and spatial scales. Likewise we agree that extant community assemblages generally did not co-evolve *in situ*. Interim NPS "impairment" policies and the normative concepts of ecosystem sustainability, integrity, and health all are based on dynamic rather than static views of community / ecosystem structure and function. In principle, all consider ecosystem condition in relation to some accepted range of variability, often defined with reference to an earlier time period (e.g., Cole et al. 1997) or to extant ecosystems presumed to be relatively unaffected by human activities (e.g., Kleiner and Harper 1972, Madany and West 1983). There are numerous practical and theoretical challenges associated with the use of such temporal or spatial benchmarks, but these benchmarks nonetheless provide managers with important information about variability that otherwise would be lacking (White and Walker 1997, Landres et al. 1999, Millar and Woolfenden 1999, Stephenson 1999, Swetnam et al. 1999, Allen et al. 2002, Parrish et al. 2003). The critical need is to define and describe benchmark conditions as explicitly as possible in terms of "acceptable" variability so that monitoring can be designed and data can be interpreted within some context. This challenge will be prominent during the Phase III process because such issues are inherent (or should be inherent) in the development of sampling designs. Because of the problems associated with strict spatial comparisons (uncertainty regarding site matches) and strict historical comparisons (uncertainty regarding the applicability of historic environmental conditions), NCPN likely will follow recommendations of White and Walker (1997) and identify benchmark conditions on the basis of a variety of information sources.

I see no contradiction between the NPS impairment mandate and contemporary ecological theory concerning ecosystem dynamics. In the Phase I and Phase II reports, we have used the term "state" for convenience, but in no way do we interpret this term in a truly static sense. "Domain" may be a more precise term for the intended meaning (e.g., Scheffer et al. 2001, Beisner et al. 2003). The dynamic interpretation of "state" is reflected explicitly throughout the Phase I and Phase II documents (e.g., dynamic states described by an acceptable range of variability). A cause for misunderstanding may be that Young et al. (2001) use the term "state" differently than it has been used in NCPN documents.

<u>On "acceptable" variability</u> – A general assumption underlying the management of "natural areas" (including most NPS lands) is that, to the degree possible, human impacts on ecological processes should be minimized. In this context, "natural" is defined to mean "with minimal human influence." This assumption is so obvious to NPS staff that it is rarely made explicit. Nevertheless, it is reflected in Tables 1 and 2 of the Phase II report, where NPS management objectives pertinent to vital-signs monitoring are listed. An important purpose of monitoring is to differentiate "natural" or inherent variability from anthropogenic variability. [I will avoid digressing further into an academic discussion concerning the naturalness of human activities.]

<u>On the issue of species additions</u> – Generally speaking, nonnative (exotic) species represent undesirable components of anthropogenic variability. Cases exist in which nonnative species can be used to help achieve conservation goals (e.g., soil stabilization), but nearly as many cases exist in which well-intentioned introductions have had unintended consequences contrary to conservation goals (e.g., Bock et al. 1986, Callaway et al. 1999). While it is true that the vast majority of introduced species have had relatively minor impacts on the structure and functioning of native ecosytems, contrary examples are numerous and dramatic. Views of Johnson and Mayeux (1992) notwithstanding, there is ample evidence to justify policies that aim to minimize the establishment and spread of nonnative species for purposes of conserving native biodiversity.

Literature Cited

Allen, C. D., M. Savage, D. A. Falk, K. F. Suckling, T. Schulke, T. W. Swetnam, P. B. Stacey, P. Morgan, M. Hoffman, and J. T. Klingel. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: A broad perspective. *Ecological Applications* 12: 1418-1433.

Beisner, B. E., D. T. Haydon, and K. Cuddington. 2003. Alternative stable states in ecology. *Frontiers in Ecology and Environment* 1: 376-382.

Bock, C. E., J. H. Bock, K. L. Jepson, and J. C. Ortega. 1986. Ecological effects of planting African lovegrasses in Arizona. *National Geographic Research* 2: 456-463.

Callaway, R. M., T. H. DeLuca, and W. M. Belliveau. 1999. Biological-control herbivores may increase competitive ability of the noxious weed *Centaurea maculosa*. *Ecology* 80: 1196-1201.

Scheffer, M., S. Carpenter, J. A. Foley, C. Folke, and B. Walker. 2001. Catastrophic shifts in ecosystems. *Nature* 413: 591-596.

Cole, K. L., N. Henderson, and D. S. Shafer. 1997. Holocene vegetation and historic grazing impacts at Capitol Reef National Park reconstructed using packrat middens. *Great Basin Naturalist* 57: 315-326.

Johnson, H. B., and H. S. Mayeux. 1992. Viewpoint: a view on species additions and deletions and the balance of nature. *Journal of Range Management* 45: 322-333.

Kleiner, E. F., and K. T. Harper. 1972. Environment and community organization in grasslands of Canyonlands National Park. *Ecology* 53: 299-309.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications* 9: 1175-1188.

Madany, M. H., and N. E. West. 1983. Livestock grazing-fire regime interactions within montane forests of Zion National Park, Utah. *Ecology* 64: 661-667.

Millar, C. I., and W. B. Woolfenden. 1999. The role of climate change in interpreting historical variability. *Ecological Applications* 9: 1207-1216.

Parrish, J. D., D. P. Braun, and R. S. Unnasch. 2003. Are we conserving what we say we are? Measuring ecological integrity within protected areas. *BioScience* 53: 851-860.

Stephenson, N. L. 1999. Reference conditions for giant sequoia forest restoration: Structure, process, and precision. *Ecological Applications* 9: 1253-1265.

Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: Using the past to manage for the future. *Ecological Applications* 9: 1189-1206.

White, P. S., and J. L. Walker. 1997. Approximating nature's variation: Selecting and using reference information in restoration ecology. *Restoration Ecology* 5: 338-349.

Young, T. P., J. M. Chase, and R. T. Huddleston. 2001. Community succession and assembly: Comparing, contrasting, and combining paradigms in the context of ecological restoration. *Ecological Restoration* 19: 5-18.

2. *Reduce or Further Prioritize "Vital Signs" Lists to Fit Slim Budgets.*

Response: We acknowledge that the lists of vital signs presented in this report describe a monitoring program that appears far more comprehensive than can be supported with base funding from the I&M Program. Much work remains to be done to further prioritize and reduce the set of monitoring tasks. This effort will continue during the Phase III process, which will include assessments of how multiple vital signs can be monitored efficiently via integrated data-collection efforts. In particular, we intend to work with outside cooperators to investigate the utility of various remote-sensing technologies for spatially extensive monitoring of integrated suites of vital signs. This type of approach could work well with cyclic or rotational sampling schemes in which remotely sensed data are acquired for a small subset of parks during one year and for another subset of parks during the following year. Complete network coverage could be obtained by rotating sampling efforts among parks over a five-year period.

Clearly, not all vital signs can be monitored remotely. Intensive ground-based monitoring will only be possible for a small number of vital signs at a relatively small number of locations. The selection of these vital signs and locations will depend on specific monitoring questions and on assessments of relative degrees of risk. Key questions are:

- What changes are most probable? – where and when?
- What changes are least acceptable in relation to management objectives? – where and when?
- What changes are least reversible? – where and when?

Early during the Phase III process, a major effort will be devoted to devloping specific monitoring questions and addressing risk-assessment questions for purposes of monitoring design.